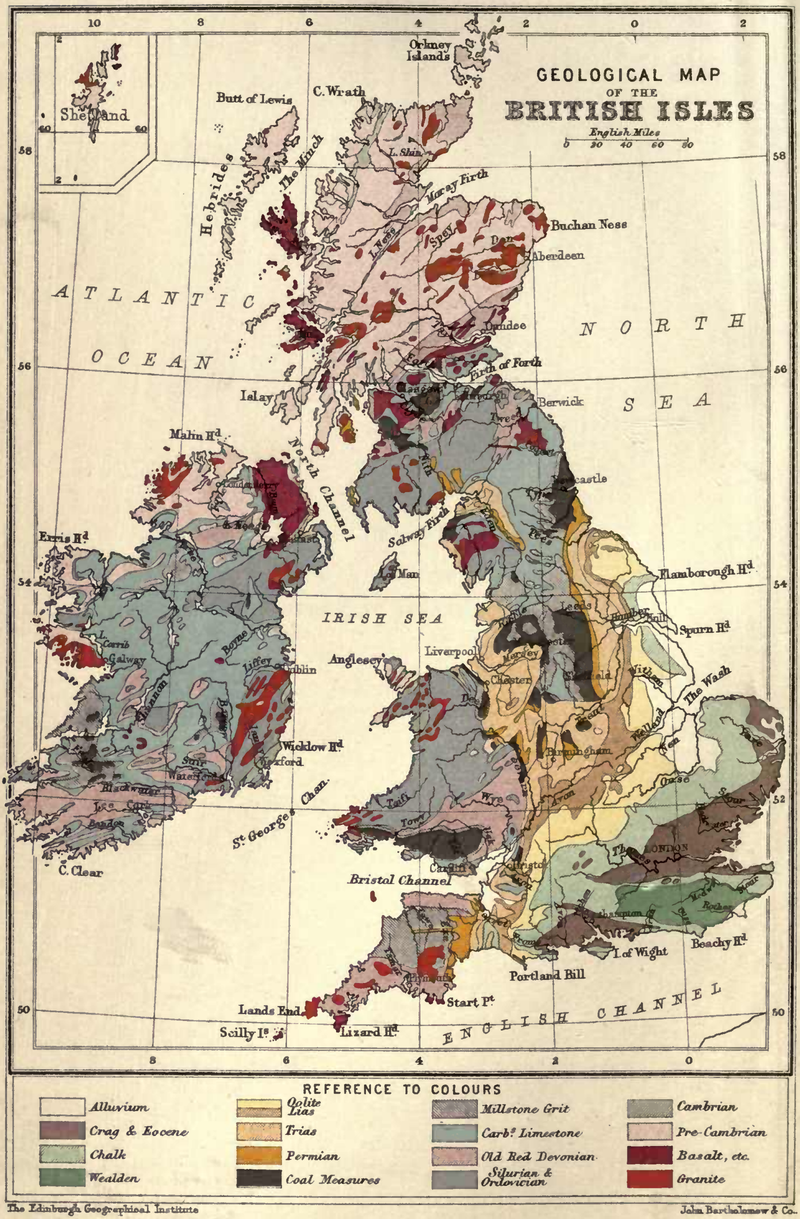
R H Loughridge

AGRICULTURAL GEOLOGY

BY THE SAME AUTHOR

THE SCIENTIFIC STUDY OF SCENERY

THE PRINCIPLES OF STRATIGRAPHICAL GEOLOGY



GEOLOGICAL MAP OF THE BRITISH ISLES
English Miles
0 20 40 60 80
Shetland
Orkney Islands
Butt of Lewis
C. Wrath
Hebrides
The Minch
Moray Firth
Buchan Ness
Aberdeen
Dundee
Firth of Forth
Berwick
ATLANTIC OCEAN
NORTH SEA
Islay
Malin Hd.
North Channel
Newcastle
Solway Firth
Erris Hd.
Flamborough Hd.
Spurn Hd.
IRISH SEA
Liverpool
Anglesey
Chester
Leeds
Galway
Dublin
The Wash
Birmingham
Wicklow Hd.
Wexford
Waterford
St. George's Chan.
C. Clear
Cardiff
Bristol Channel
LONDON
I. of Wight
Beachy Hd.
Portland Bill
Start Pt.
Lands End
Scilly Is.
Lizard Hd.
ENGLISH CHANNEL
REFERENCE TO COLOURS
Alluvium
Crag & Eocene
Chalk
Wealden
Oolite
Lias
Trias
Permian
Coal Measures
Millstone Grit
Carb. Limestone
Old Red Devonian
Silurian & Ordovician
Cambrian
Pre-Cambrian
Basalt, etc.
Granite
The Edinburgh Geographical Institute
John Bartholomew & Co.

AGRICULTURAL GEOLOGY

BY

J. E. MARR, M.A., F.R.S.
FELLOW OF ST. JOHN'S COLLEGE, CAMBRIDGE

WITH A COLOURED GEOLOGICAL MAP AND 104 DIAGRAMS

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PREFACE

THIS book has been written, after study of the schedule framed for the guidance of candidates for the International Diploma of Agriculture, to be used by students who are reading for examinations in Agriculture, though it may be found useful to others.

The writer has utilised the descriptions of the soils formed above the various British strata which are given in Mr. H. B. Woodward's admirable *Geology of England and Wales*, to which he refers his readers for further information concerning the British strata. He also offers his thanks to the author of that work for leave to make use of those descriptions.

The writer's thanks are also due to Mr. R. Etheridge, F.R.S., and to Messrs. Charles Griffin and Co., who are respectively editor and publishers of the late Professor Phillips' *Manual of Geology*, for permission to use the Geological Map of the British Isles which is inserted in that work. This map, with slight alterations, forms the frontispiece to the present volume.

J. E. M.

CAMBRIDGE, *January*, 1903

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CHAPTER I

INTRODUCTION

THE student of agriculture is no doubt chiefly concerned with the thin covering of soil which in so many parts of the land conceals the solid rocks beneath; but a knowledge of these rocks is by no means useless to him. In the first place, much of the material which composes the soils is derived from the underlying rocks, and therefore varies according to their composition. The soil of a country composed of chalk is very different from that of an area where red sandstone is the prevailing rock, or of one in which clay is found beneath the soil.

Again, the degree in which the underlying rocks are pervious to water is important, not only on account of the influence which is exercised upon the soil above—a porous rock causing the soil to be drier than a less porous one—but also because of the dependence of water-supply on the porosity of the underlying rocks. An acquaintance with the elementary facts of geology, and with the general principles of the science, may often save a farmer the trouble and expense of securing the services of an expert in order to obtain a supply of water.

Many of the rocks which compose the earth's crust are serviceable to the agriculturist, or contain substances which are of service to him. It is useful to be able to know what rocks may be utilised for building purposes, for road-metal, and for fertilising the soil.

Should he find it necessary to make road-cuttings, or to excavate pits or quarries on his property, it is important that he should have some acquaintance with the nature of the divisional planes which traverse rocks.

Lastly, although he is not directly concerned with the mineral substances which may exist beneath his land, which are not useful for agricultural purposes, the knowledge of the distribution of substances like coal and ores may prove to be very serviceable.

For such reasons the subject of geology has been rightly included among those subjects of which a knowledge is required by candidates for an agricultural diploma. It is obvious, however, that much which may be of interest and importance to the student who pursues the study of geology for its own sake, or to one who is concerned with it mainly on account of its bearing upon the discovery of valuable minerals and ores, is of no importance to the agriculturist, and therefore it is not necessary for him to follow in detail the various branches of the science as they are treated in ordinary geological text-books.

The student of agriculture should, in the first place, possess a knowledge of the general characters and composition of the most important rocks, and should study the nature of the divisional planes which affect those rocks. When studying this part of the subject he should be made acquainted with the properties of those rocks which are suitable for building-stones or for road-metal, as well as of those which yield important fertilising substances.

A general acquaintance with the work of various geological agents, such as frost, wind, rain, and rivers, is important, and a knowledge of the work of these agents will tend to render clear the conditions which bring about and control soil-formation and water-supply.

The movements which have tilted and broken the rock-layers in many parts of the earth should be then considered, and a knowledge of the effects of these movements will enable the student to understand the mode of construction of geological maps, for the interpretation of these is a matter of very considerable importance.

As the nature of soils is often dependent, to a considerable degree, upon climatic conditions, a brief consideration of the effects of climate upon soils will be of use. It may be here observed that though a study of meteorology does not come directly within the domain of the geologist, it is so important to the student of agriculture that some attention might well be devoted to it, though it cannot be considered in the present work. Those who are concerned with agriculture are usually so well versed in the signs of the sky as indicating changes of weather, that they are particularly well qualified to study coming changes by combining the results of the observations with the intelligence which they can obtain from a study of barometric changes and from perusal of published weather charts. It would be well if those who desire to reap the full benefit of their power of foretelling the weather would peruse some work like the book upon *Weather*, by the Hon. R. Abercromby, published as one of the "International Scientific Series."[1]

It is the province of the geologist to attempt to write a connected account of the history of the earth by studying the various rocks in the order in which they have been formed. This order is of subsidiary importance to the agriculturul student, who, however, should know something of the differences which characterise the rocks of different ages in his own country. This knowledge will be more easily obtained and retained if the rocks be studied in definite order. As rocks of one age differ very considerably when traced from one country to another, it cannot be expected that anyone desirous of obtaining a knowledge of geology as bearing upon agriculture should burden his memory with details concerning the rocks of all regions of the earth's surface, and it is recommended that inhabitants of the British Isles should confine their attention almost exclusively to the rocks which exist in these islands. Fortunately, the geology of the British

[1] *Weather: A Popular Exposition of the Nature of Weather Changes from Day to Day.* By the Hon. Ralph Abercromby. London: Kegan Paul, Trench, Trübner, and Co.

Isles is, to a great extent, an epitome of the geology of the world, so far as this is known to us, and it will only be necessary to supplement a study of the rocks of Great Britain by occasional reference to those of other lands which supply materials of economic importance, such as fertilisers.

In the present work it is proposed to treat of the subject in the order outlined in the preceding paragraphs. This order may be rendered clearer if we divide the subject into three groups, as follows :—

(i) The study of the composition and structures of rocks.

(ii) The study of geological agents and their effects.

(iii) The study of the rocks and their included fossils in the order in which the rocks were deposited.

It is inevitable that portions of the different groups should overlap to some extent, but an attempt will be made to avoid any needless repetition.

Section I

THE STUDY OF THE COMPOSITION AND STRUCTURES OF ROCKS

CHAPTER II

ROCKS: THEIR NATURE—CLASSIFICATION OF ROCKS

THE geologist is accustomed to speak of any aggregate of mineral particles as a rock, without any reference to its hardness or state of coherence; thus a loose sand is to him a rock, as well as a hard granite. According to this definition, soil would be classed as a rock. The geological surveyor, however, is induced to separate the "solid rocks" beneath from the "superficial accumulations" above, and although this separation cannot be rigidly carried out, for in some regions no sharp line can be drawn between the two groups, it is readily applicable in nearly all parts of Britain; and as it is one which is peculiarly important to the student of agriculture, it will be generally adopted in this treatise; and when special intimation is not given, the term rock will be applied to the "solid rock" of the earth's crust, and soils, alluvia, glacial deposits, and similar incoherent accumulations will be considered as "superficial accumulations." These in many places form, as it were, a blanket over the solid rocks, and a special term has been adopted for them by some American writers; but in a work like the present it is unnecessary to make excessive use of technical terms and to insist upon too rigid definitions, and the above distinctions will be found sufficient for practical purposes.

Rocks are divided into two great groups, the *Igneous* rocks, which have consolidated from a state of fusion, like granite and basalt, and the remainder, which have been formed as accumulations and deposits at the earth's surface, above or below water, though especially below the sea. The latter are variously named *Aqueous* rocks, *Sedimentary* rocks, or *Stratified* rocks. Objection may be made to each of these terms, as not including certain rocks which are non-igneous; but for our purposes any one of the terms is sufficient, though the term Stratified is perhaps least open to objection, and will be adopted.

A difficulty may be felt in grouping the rocks which are formed by ejection from volcanoes in a solid though fragmental condition, such as volcanic ashes. For our purpose it will be convenient to include these under the head of Igneous Rocks, which they closely resemble in composition.

A third group of rocks is sometimes introduced under the title of *Metamorphic* rocks. These have undergone much alteration since their formation. Since both igneous and stratified rocks have been metamorphosed, it is unnecessary to make a special group for these rocks, though something must be said concerning their characters.

It is supposed that the earth was at one time a mass of liquid rock, and that on cooling it became consolidated, at any rate so far as its crust is concerned. According to this view, the rocks which were first formed upon the earth's surface must have been igneous rocks, and any subsequently formed stratified rocks must have been formed of materials derived directly from igneous rocks, or else indirectly from them, owing to the breaking up of other sediments. It is true that some constituents of rocks might be derived from the sea-waters or from the atmosphere, but these constituents play a minor part in the formation of sediments.

In order, therefore, that we may understand the significance of the composition of the sedimentary rocks, it behoves us, at the outset, to consider the characters and composition of the various igneous rocks.

IGNEOUS ROCKS

The classification of igneous rocks is made by taking into account their chemical composition and their physical characters, and it will be convenient if we consider the physical characters at the outset, and afterwards pass on to a discussion of the chemical composition of this group of rocks.

The most important differences among igneous rocks, with regard to their physical characters, are dependent upon the conditions under which they have consolidated, and a short reference must therefore be made to these conditions.

Firstly, we may note that whereas some rocks are poured out in a molten condition at the earth's surface as *Extrusive* rocks, others have consolidated beneath the surface. Of the latter a large number have undoubtedly been forced, when in a molten condition, between pre-existing solid rocks, and have subsequently cooled; these are *Intrusive* rocks. In addition to these there are masses of rock which, having been once molten, may have consolidated in the position in which they were when they became melted, without having been forced away to other places. These rocks cannot, strictly speaking, be termed intrusive, though they resemble the true intrusive rocks in many respects, and we will not dwell further on their distinction from those rocks. Some of the rocks which have consolidated beneath the surface have become solid at a much greater depth than others. The rocks which have consolidated at a great depth are known as *Plutonic* rocks. They often occur in great masses, frequently many miles in diameter. The exact nature of these masses is still to some extent obscure. As examples of such plutonic masses, we may instance the granites of Devon and Cornwall, of Wicklow, and of many parts of Scotland. These masses often possess offshoots, resembling, in the manner in which they pierce the surrounding rocks, the igneous rocks which have been intruded at a higher level. In Fig. I an attempt is made to show the modes of occurrence of the igneous rocks at varying levels, and as little is known concerning the bases of the great plutonic masses, no attempt is made to show the base of such a mass in this diagram.

Between the plutonic rocks and the rocks which are formed at the surface of the earth we observe in the diagram a group of rocks which are spoken of as

Intrusive[1] rocks (though true intrusive rocks are also associated with the plutonic and the volcanic groups). The intrusive rocks have been forced among pre-existing solid rocks, and they naturally take advantage of the planes of weakness existing in these rocks in the form of bedding-planes and various cracks. If they

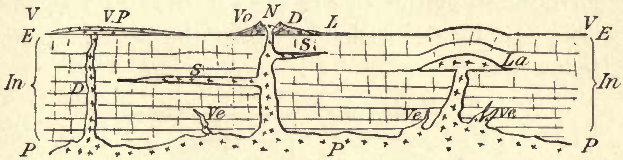


FIG. 1.

SECTION THROUGH A PORTION OF THE EARTH'S CRUST.

Showing modes of occurrence of Igneous Rocks.

The thin horizontal lines with broken vertical lines are drawn through Sedimentary Rocks; the Igneous Rocks are represented by crosses. The parts *V V* above the former earth's surface show Volcanic Rocks. The portion between *P P* represents Plutonic Rocks. The parts marked by crosses between these exhibit Intrusive Rocks.

D=Dykes. *Ve*=Veins. *S*=Sills. *La*=Laccolite.
Vo=Volcano. *VP*=Volcanic plateau. *N*=Neck.
L=Lava-flow.

The scale of the Dykes and Veins is much exaggerated, and that of the Plateau diminished.

consolidate along vertical, or nearly vertical, cracks, they are termed *dykes*, and form wall-like masses, as seen in Fig. 1 and more clearly in Fig. 2. Should they be forced along horizontal, or nearly horizontal, planes, they are termed *sills* when the upper and lower surfaces are practically parallel, and *laccolites* if the mass of igneous rock assumes a mushroom-shaped

[1] The term is here used in a more limited sense than when used on p. 12.

outline. When strings of igneous material are forced more or less irregularly through the rock, these strings are called *igneous veins.* Lastly, should igneous rock consolidate in the pipe of a volcano, it is termed a *volcanic neck.* Such a neck will be a more or less vertical, cylindrical plug of igneous rock, and it will be surrounded by the rock of the volcano in its higher portion, and by the rocks on which the volcano rests in its lower part.

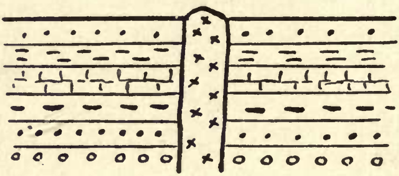


FIG. 2.
SECTION ACROSS A DYKE.
The Dyke is marked by crosses. The other signs indicate various sediments, through which the dyke has been forced.

At a higher level than the intrusive rocks are the *Volcanic* rocks, which are consolidated at the surface as lava-flows, or are forced between rocks near to the surface, as is the case with the upper parts of volcanic necks, and the dykes, sills, and veins, which may be often found forced into the cracks of a volcano. We shall have occasion in a subsequent chapter to refer more fully to the characters of volcanoes.

It will be seen from the foregoing remarks that a classification of rocks into—

Volcanic Rocks,
Intrusive Rocks,
Plutonic Rocks,

may be made with reference to the depth under which these rocks have consolidated. From what has been said it will be gathered that this classification is only a rough one, but it will be found sufficient for our present purpose. It now remains for us to consider the physical differences in the rocks themselves, which are due to the differences of condition under which they have consolidated.

If we melt a piece of granite, which is *crystalline* rock, in a furnace and allow it to cool very rapidly, it will consolidate as a piece of *glass*. If, on the other hand, we melt a piece of glass and allow it to cool with extreme slowness, though it will not resemble granite, it will not be glass, but will possess a crystalline structure. From these experiments we learn that molten material may assume the *crystalline* or *glassy* condition when cooled, according to the rate of cooling. Further experiments on various substances would show that, other things being equal, the slower the rate of cooling, the larger would be the crystals which were formed. Now as a rule the greater the depth from the surface, the slower would be the rate of cooling of a molten rock; and accordingly we may expect to find the coarsely crystalline rocks occurring chiefly in the case of the plutonic group, more finely crystalline rocks among those of the intrusive group, and very finely crystalline and glassy rocks among the volcanic group—and this is what we actually do find. The plutonic rocks are all *holocrystalline*, that is, entirely crystalline: no glass occurs in a plutonic rock.

A crystal is bounded by natural faces, which are symmetrically arranged with reference to certain lines known as axes. A perfect crystal must have room in which to grow, and the first-formed crystals of a rock could grow freely in the liquid mass, and may possess the proper crystal outline characteristic of the mineral; but the later-formed crystals cannot grow freely, as they are obstructed by those already formed, and must accommodate their outlines accordingly. Therefore no igneous rock is composed of perfectly formed crystals. The crystals are either partly perfect and partly imperfect or all imperfect.

There are certain structures which are found in volcanic rocks, and to some extent in intrusive rocks, which are absent from plutonic rocks. These will be noted when we describe the characters of the volcanic rocks.

The intrusive rocks are also chiefly holocrystalline, though the crystal grains are usually smaller than those of the plutonic rocks; and in some cases glass is found, especially towards the margins of the rock-masses.

The volcanic rocks may be crystalline or glassy. The great bulk of glassy rocks which have been discovered are volcanic, and when the rocks are crystalline the crystals are often minute, so that they cannot be detected by the naked eye.

There are a number of other features characteristic of or occurring chiefly among volcanic rocks, which may be conveniently noticed here.

Igneous rocks contain a greater or less amount of water, which under great pressure retains the liquid form, even when at a very high temperature. As the liquid rock rises towards the surface, and the pressure is diminished, this water may flash into vapour; and if the vapour cannot escape, a more or less globular cavity will be formed within the rock. As the water is frequently scattered through the rock in minute droplets, each of which gives rise to one of these gas cavities on the vaporisation of the water, the cavities, or *vesicles*, as they are termed, may be thickly scattered through the rock, as shown in Fig. 3, when the

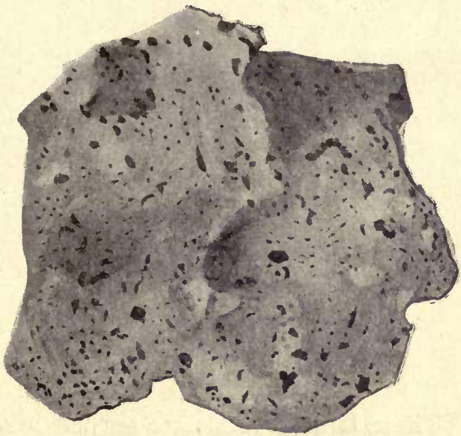


FIG. 3.
VESICULAR STRUCTURE IN LAVA.
The black portions represent the vesicles.

rock is termed *vesicular*, or, if the vesicles are very abundant, *pumiceous*, as pumice furnishes a typical case. These vesicles are very frequent in volcanic rocks, especially on the upper and under surfaces of lava-flows, and they occasionally occur in the intrusive rocks also, but, as already stated, never in plutonic rocks.

In ancient rocks the vesicles are often filled with some mineral which has been introduced into the cavities by infiltration. These minerals are often of a white colour, and the rock appears as though studded with almonds; hence these rocks with refilled cavities are called *amygdaloidal* rocks.

In lavas, and to some extent in intrusive rocks, large crystals are frequently found embedded in the glassy or finely crystalline *ground-mass*, as shown in

FIG. 4.

PORPHYRITIC STRUCTURE.

The light portions are porphyritic crystals.

Fig. 4. These large crystals are termed *phenocrysts*, and a rock containing them is said to be *porphyritic.* The phenocrysts were formed at an earlier stage of consolidation than the ground-mass, when the fluid rock was more deeply seated, and the material could therefore consolidate more slowly.

Volcanic rocks and, more rarely, intrusive rocks possess various structures known as flow-structures, due to differential movement of the fluid-mass during its transference from one place to another. If clots of different structure or composition are found in the fluid-mass, these may be dragged out into long, ribbon-like strips, running parallel to the direction of flow. In this way a banded structure is produced, as shown in Fig. 5, where the bands have subsequently been bent into sharp folds as the result of further movement of the mass. Minute crystal bodies, known as microlites, may also be arranged with their longer

FIG. 5.
FLOW-STRUCTURE IN LAVA.

axes lying parallel to the direction of flow, and when a rock is porphyritic, the microliths may be observed streaming round the phenocrysts as bits of straw would stream round either side of a stone projecting from the water of a flowing brook. Again, the vesicles are often dragged out into ellipsoidal hollows, having their longer axes lying parallel with the direction of flow, and the amygdaloids resulting from the infilling of these cavities naturally possess the same shape.

Certain flow-structures resembling to some extent the banded structures found in volcanic rocks occur also in plutonic rocks, as the result of movements prior to the consolidation of those rocks, and may readily be confused with structures produced after consolidation as the results of earth-movement.

Two other structures which are mainly found in volcanic rocks are known as *sphærulitic* and *perlitic* structures. *Sphærulites* (Fig. 6) consist of crystal rods arranged radially around definite centres, and giving rise to more or less spherical masses in the

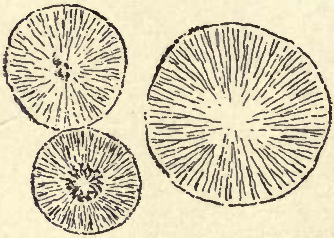


FIG. 6.

SPHÆRULITIC STRUCTURE.

rock. If the sphærulites are numerous and contiguous, they may interfere with one another, forming polygonal boundaries. The sphærulites are often arranged in definite bands in the rock. They may be of very different sizes; a common size is that of a pea, though giant sphærulites are often much larger.

Perlitic structure (Fig. 7) is also marked by the existence of sphæroidal bodies in the rock. These are curved cracks produced by contraction of the rock round definite centres.

Having now noticed the principal distinctions between the rocks of the volcanic, intrusive, and plutonic groups, we may proceed to consider how the rocks may be grouped by reference to differences of chemical composition.

It has been stated that a rock is an aggregate of mineral particles; but in order to understand this definition we must have some conception of the significance of the term mineral. A mineral may be defined as a homogeneous inorganic substance having

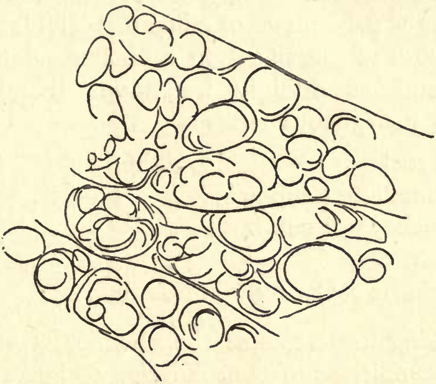


FIG. 7.

PERLITIC STRUCTURE.

a definite chemical composition and constant physical characters. To determine a mineral, therefore, we may either ascertain its chemical composition or its physical characters, or both of these. A mineral may consist of a chemical element, as sulphur or native iron, or of a compound of two or more elements.

The elements are divided into two groups, the metals and non-metals. The metals and non-metals may combine with oxygen to form oxides. The oxides of the metals are called *basic* oxides, or, more commonly, bases. Those of the non-metals form *acid* oxides (for our purpose acids). Acids and bases may act upon one another to form salts, which are combinations of acids and bases. The non-metallic oxide which forms the acid component of the great bulk of rocks is the oxide of silicon, or *silica*. There are several bases, as soda, potash, alumina, lime, magnesia, and iron oxides. Igneous rocks are therefore divided into *acid* and *basic* groups, the former containing a much larger percentage of silica than the latter. For the purpose of classification a further subdivision is useful, and accordingly we adopt the following divisions for igneous rocks:—

Acid rocks		contain	65–80 %	of silica.
Intermediate rocks	sub-acid	„	60–65 „	„
	sub-basic	„	55–60 „	„
Basic rocks		„	45–55 „	„
Ultrabasic rocks		contain less than	45 „	„

By taking into account the chemical composition and the conditions of consolidation of igneous rocks, we may classify them as in the following table:—

	Acid rocks. 65-80 % silica	Intermediate rocks.		Basic rocks. 45-55 % SiO_2	Ultrabasic rocks. Less than 45 % SiO_2
		Sub-acid. 60-65 % SiO_2	Sub-basic. 55-60 % SiO_2		
Plutonic rocks	Granite	Syenite	Diorite	Gabbro	Serpentine
Intrusive rocks	Quartz Porphyry	Quartzless Porphyry	Porphyrite	Diabase	
Volcanic rocks	Rhyolite and Obsidian	Trachyte	Andesite	Dolerite and Basalt	

In this table the names of the commoner and more representative rocks only are given. The student of petrology is concerned with the study of a large number of rocks, many of which are of extreme rarity; but for our present purpose a study of the most typical members of each division will be sufficient to allow us to obtain some idea of the nature of the great bulk of igneous rocks.

The names of many of the rocks mentioned in this table were originally applied somewhat vaguely; and although attempts have been made to use them with definite significations, writers are not always agreed as to the precise aggregate of minerals to which some of these names should be applied. Each name, however, refers to a rock due to an aggregate of mineral particles; and in order to ascertain the nature of a rock we must be able to identify its component minerals. A very large number of minerals are known to the mineralogist, but many of them are very rare; and the student who wishes to identify the common and important rocks can usually do so if he is capable of making accurate identifications of a few minerals, of which a list will presently be given.

It was stated above that a mineral had a definite chemical composition and constant physical characters, and accordingly we may utilise our knowledge of either chemical composition or physical characters, or both, in order to identify a mineral. The most certain way of finding out is to observe the physical characters, and also to ascertain the chemical composition of the mineral under consideration. The discovery of the chemical composition is usually, however, a matter requiring much time and care, for the different kinds of mineralsforming a rock must be separated from one another—often by difficult processes—and each subsequently subjected to analysis.

Geologists usually identify minerals as the result of observation of physical characters only, but many of these can only be studied successfully by examining thin rock-slices under a microscope.

Certain characters of minerals can often be noted in hand-specimens, and it is to these that we must here confine our attention. It must be distinctly understood that in many cases the examination of physical properties in hand-specimens gives but an uncertain indication of the nature of the mineral which is being inspected; the number of physical characters of a mineral on which we can rely for its identification is not very large, and accordingly more than one mineral may possess the same characters as observable in hand-specimens. Hence it is that the student of rare rocks containing uncommon minerals has frequently to resort to chemical analysis. In the case of the comparatively few minerals composing the common rocks with which we propose to deal in this volume, the rough-and-ready methods of identification based on the study of the mineral characters as observable in hand-specimens must, however, suffice.

Among characters of importance for identification of minerals are *hardness*, *lustre*, *cleavage*, *crystalline form*, *density*, *colour*, *taste*. Of these, the three first-mentioned are the most generally useful, for crystalline form is not often noticeable except in the minerals which have first consolidated; colour varies much in the same mineral: for instance, quartz may be colourless, smoky, pink, or violet; and there are not many minerals which possess a definite taste.

Other characters of which we sometimes make use are the *streak* or colour of a powdered portion of the mineral as seen when rubbed on a piece of white paper or porcelain; and *twinning*, to which allusion will be made when considering the characters of felspars.

We may now proceed to discuss the mode of utilising the different characters of minerals, in order to determine the nature of the mineral; and although crystalline form is not often of use in identifying the minerals of igneous rocks, it will be convenient to consider it at the outset.

CRYSTAL SYSTEMS.—Every mineral has a definite shape, possessing a certain degree of symmetry. It consists of a geometrical form bounded by definite *faces;* corresponding faces need not necessarily be of the same size, but the *angle between corresponding faces in different specimens of the same mineral is constant.* The faces may be regarded as being developed around certain lines which are spoken of as *axes* of the crystals; and according to the nature of these axes, all crystals can be referred to six crystalline systems.

Suppose that we take a cube, which possesses six square faces. If we take a point in the exact centre of each face and draw lines between the points of opposite faces, we shall find that there are three such lines of equal length at right angles to each other. Fig. 8 shows a cube, the axes being indicated by dotted lines, which is also the case with the figures illustrating the other five systems. Minerals belonging to the system which is characterised by crystals possessing three equal axes at right angles to one another are said to belong to the *cubic system.* Other

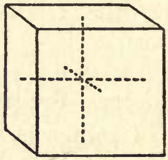


FIG. 8.
CUBIC CRYSTAL.

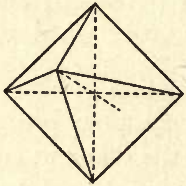


FIG. 9.
REGULAR OCTAHEDRON.

forms besides the cube belong to this system; for instance, if the axes join the angles of the crystal instead of the centres of the faces, we get the regular octahedron, which has eight faces, each forming an equilateral triangle (see Fig. 9).

Suppose that, the axes being all arranged at right angles, as before, we add to one of the axes, so that it is longer than the other two, and that we make the addition in such a way that the other two axes cut the long one in its centre; we still have three axes at right angles to one another, but two are of equal length, and the third is unequal to either of the others. The third axis may be spoken of as the *vertical axis.* Crystals built up around such an arrangement of axes are said to belong to the *tetragonal system* (see Fig. 10).

The third system includes crystals, which are again built up around three axes at right angles to one another, but in this system—known as the *trimetric system*—all the axes are of unequal length (Fig. 11).

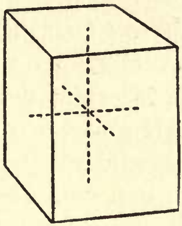


FIG. 10.

TETRAGONAL SYSTEM.

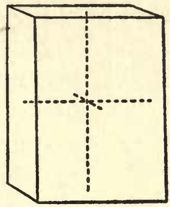


FIG. 11.

TRIMETRIC SYSTEM.

In the fourth system the three axes are unequal, as in the case of the third, and the *lateral* axes are at right angles to one another, as before, but the vertical axis is inclined obliquely to the lateral axes. This is the *monoclinic system* (Fig. 12).

In the fifth or *triclinic system* all the axes are unequal and oblique to one another (Fig. 13).

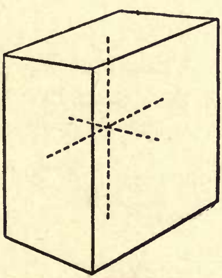


FIG. 12.

MONOCLINIC SYSTEM.

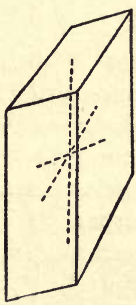


FIG. 13.

TRICLINIC SYSTEM.

The sixth system possesses four axes. The three lateral axes are of equal length and make angles of sixty degrees with one another. The vertical axis is not equal to a lateral axis, and is at right angles to the lateral axes. This is the *hexagonal system* (see Fig. 14).

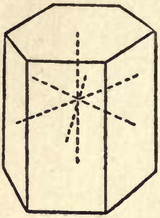


FIG. 14.
HEXAGONAL SYSTEM

Space does not allow us to enter into further detail concerning the shapes of crystals belonging to the different systems, but the student is recommended, should he desire to pursue this subject further, to obtain access to a set of crystal models, and to study them with the assistance of an elementary work upon crystallography or mineralogy.

HARDNESS.—The mineralogist refers all minerals to a scale of hardness, numbered from one to ten, each number representing a particular standard mineral.

The following, which is known as Moh's scale of hardness, is that which is adopted :—

1. Talc	Scratch with finger-nail	Scratched by a knife easily.
2. Rock-salt		
3. Calcite		
4. Fluor-spar		
5. Apatite	Knife scratches with difficulty.	
6. Felspar		
7. Quartz	Cannot be scratched by a knife.	
8. Topaz		
9. Sapphire		
10. Diamond		

The minerals with a hardness 8–10 are rarely met with, and the student of rocks is chiefly concerned with those numbered 1–7. A rough method of obtaining the degree of hardness is available by using the finger-nail and a pocket-knife. Minerals may be divided into (1) those which scratch with the finger-nail; (2) those which, not being scratched with a finger-nail, can be *easily* scratched with a knife; (3) those which a knife will scratch with *difficulty;* and (4) those which *cannot* be scratched with a knife.

The relationship of the hardness of minerals thus determined to those represented in Moh's scale of hardness is indicated in the above table.

The student may at first meet with some difficulty in distinguishing those minerals which are scratched by a knife with difficulty from those which will not scratch at all, as the latter show a mark due to particles of the knife adhering to them. He will do well to practise with a piece of felspar, which is scratched with difficulty, and a piece of quartz, which cannot be scratched at all.

Let him grasp the knife firmly by the blade itself, about a quarter of an inch from the point, press the point as hard as he can against the mineral, and draw the knife up and down two or three times, moving it about a quarter of an inch each way. After a time he will feel rather than see whether the mineral is or is not being scratched. At first he should examine the mineral with a pocket-lens at the place where the scratch was attempted, in order to see whether a scratch has actually been made, and he will ere long be able to judge without such examination whether the mineral can be scratched.

LUSTRE is due to the light reflected from the surface of a mineral, and depends upon the nature of the surface. The principal lustres are *glassy*, *pearly*, *resinous*, *silky*, *adamantine*, and *metallic*.

CLEAVAGE.—Many crystals may break or cleave more or less readily along certain planes which have definite relationships to the crystalline axes of the mineral. Thus crystals of galena will break up readily along the faces of the cube; those of fluor-spar along the faces of the octahedron. Observation of the direction or directions of the cleavage is of considerable importance in the determination of minerals. The directions are usually detected more easily in microscopic sections than when viewed with the naked eye or through a pocket-lens.

In addition to the directions, it is important to note the *degree of perfection* of the cleavage. Thus quartz has practically no cleavage; mica has perfect cleavage in one direction.

When a crystal has no cleavage, or an imperfect cleavage, the fracture depends upon the nature of the mineral. Thus quartz has a *conchoidal* fracture (resembling the curved surface of a bivalve shell); other minerals have an uneven fracture, which when jagged is spoken of as *hackly*.

TWIN-CRYSTALS.—If a simple crystal be bisected along some plane, and one half turned round, so that it presents the appearance of the other half as viewed in a mirror when held vertically to the mirror and viewed obliquely, and the two halves be now united along the plane, a twin-crystal is the result. Such crystals may often be recognised by the existence of a re-entrant angle (*i.e.* an angle of more than 180°), which never occurs in the case of a simple crystal. Broken twin-crystals may often be detected by an examination of their cleavage faces. Twins are noticed here because the two kinds of felspar, which are of importance from the part they play in our present classification of igneous rocks, may often be distinguished from each other by examination of their twin-planes, as will be more fully noticed when these minerals are described.

SPECIFIC GRAVITY.—The specific gravity of a mineral is its weight as compared with that of an equal bulk of distilled water, which is taken as unity. In accurate determination of minerals, their specific gravity is of importance. A few minerals, as sulphate of barium, known as heavy spar, may be distinguished from similar minerals by their weight, when merely handled, but this test is not often of use.

COLOUR, as already stated, is not often sufficiently constant in any mineral to aid in its identification. Several of the metallic ores, however, possess definite colours.

Other characters, as streak, taste, and smell, are of no great importance, except in certain cases, and it is not necessary to discuss them here.

CHAPTER III

ROCK-FORMING MINERALS

THE principal minerals which enter into the composition of igneous rocks may be divided into four groups, viz. silica, felspar, ferro-magnesian minerals, and ores. The minerals of these groups vary in their acidity, the first being acid, the last bases, and the intermediate ones salts.

The minerals of igneous rocks are spoken of as *original* when formed during the consolidation of the rock, or *secondary* if formed after its consolidation. The more basic the rock, the more basic are its original minerals. Thus ultrabasic rocks consist of ferro-magnesian minerals and ores; basic rocks of the more basic felspar, ferro-magnesian minerals, with the frequent addition of ores; the intermediate rocks of these, with the frequent substitution of an acid felspar for a basic one; and, lastly, the acid rocks alone contain free quartz as an abundant original constituent.

The recognition of these facts may assist the student in his determination of rocks. For instance, if he is in doubt as to whether a particular mineral is quartz or olivine, and has reason to suppose the rock is acid, the mineral will be quartz; whereas if the other evidence points to the rock being basic, the mineral is more probably olivine.

We may now proceed to an enumeration and description of those rock-forming minerals with which the student of agricultural geology may be expected to possess some acquaintance. It need hardly be pointed out that it is necessary that the student should acquire this acquaintance by examination of the actual minerals, both as individual specimens and, in the case of those which in combination with other minerals form rocks, by study of the rocks of which they form constituents.

In the following list the minerals on the left-hand side are specially found as original constituents of igneous rocks, while some of those on the right may be secondary constituents of these rocks, or may occur chiefly in metamorphic rocks or sediments.

Quartz.	Rock-salt.
Felspar.	Gypsum.
Mica.	Nitre.
Amphibole.	Kainite.
Pyroxene.	Calcite.
Olivine.	Serpentine.
Apatite.	Pyrites.
Magnetite.	

In the following descriptions the letter H is used for hardness.

DESCRIPTION OF MINERALS

QUARTZ.—Composition, silica (SiO_2). Crystallises in the hexagonal system, the crystals usually consisting of hexagonal prisms (*pr*), terminated by pyramids (*py*) (Fig. 15). No cleavage: fracture conchoidal. H = 7 (will not scratch with a knife). Lustre vitreous. Transparent to opaque. Pure quartz is

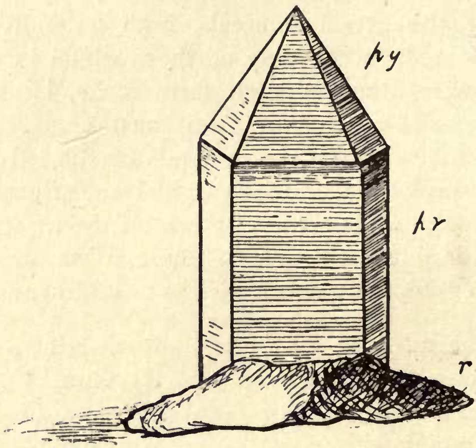


FIG. 15.

QUARTZ CRYSTAL ATTACHED TO A PIECE OF ROCK (*r*).

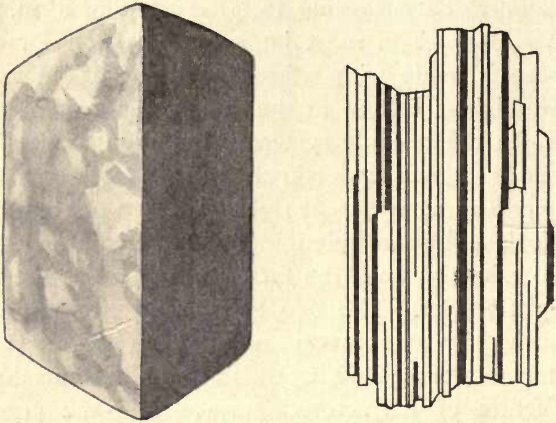
colourless; when opaque, milky white. It may, however, be coloured by various substances, and thus appear yellow, brown, rose-coloured, or purple; in rocks it often forms grains of a grey colour.

FELSPAR.—Composition, a double silicate of alumina and of a metal of the alkalies (or alkaline earths). H = 6 (scratches with difficulty). Lustre usually pearly. Colourless, or white, pink, green, etc. Usually opaque, occasionally translucent.

The group of felspars is of great importance. They are subdivided according to (i) crystalline form, (ii) composition. The most important division for our purpose is made with reference to crystalline form. Some felspars belong to the monoclinic system, and others to the triclinic system. Common monoclinic felspar is known as orthoclase, as it possesses two fairly perfect cleavages at right angles to one another. Plagioclase felspars belonging to the triclinic system are so called because the principal cleavages are not at right angles. The two types may often be distinguished by examination of the cleavages of twin-crystals. In orthoclase crystals a line often runs down the centre of a fractured surface, and the crystal appears lustrous on one side of this surface and dark on the other, when held so that the light is reflected from one face; while plagioclase is often twinned frequently, and a broken crystal appears, as though ruled by dark lines parallel to its length (see Fig. 16).

Orthoclase is an acid felspar, while most of the plagioclase felspars are more basic than orthoclase. The alkali metal which occurs in orthoclase felspar is potassium, and this felspar is therefore a double silicate of potassium and aluminium, and is commonly spoken of as potash felspar. The plagioclase felspars contain soda, lime, or both, and are spoken of as soda, soda-lime, lime-soda, and lime-felspars, these names being arranged in order of the acidity of the minerals, the soda felspar being the most acid of the four.

Orthoclase felspar is usually pink or white; plagioclase felspar rarely pink, often white or greenish. Plagioclase felspars often occur in lath-shaped crystals.



a b

FIG. 16.

a. Orthoclase felspar, showing twinning.
b. Plagioclase ,, ,, ,,

The felspars are of considerable importance to students of agriculture on account of the constituents which they furnish to soil, as will be explained in the sequel.

MICA.—Composition, hydrated silicates of alumina and potash, or alumina, magnesia, and iron. Crystallises in the monoclinic system, but simulates minerals of the hexagonal system. Has one very perfect cleavage parallel to the base of the hexagon, and thus can be easily split into thin, *elastic* flakes which are often six-sided. H = 2–3. Lustre metallic. There are two groups of mica, the white micas and the black micas. The principal species belonging to the former is *muscovite*, a potash-mica of a greyish colour with silvery lustre, while the commonest black mica is *biotite*, a magnesia-iron-potash mica—black, with a metallic lustre.

AMPHIBOLE.—Composition, lime-magnesia silicates, with iron, alumina, etc., occurring in some varieties. It crystallises mainly in the monoclinic system; crystals six-sided, often long. Two cleavages, which cross one another at angles of 120° and 60° (approximately). H = 5–6. Lustre metallic or horny. Colour usually black, sometimes green or brown. A common amphibole of the igneous rocks is *hornblende*. Needle-shaped forms of the species *actinolite* are frequent in metamorphic rocks.

PYROXENE.[1]—Composition similar to that of hornblende; also crystallises in the monoclinic system. Crystals eight-sided, often short. H = 5–6. Lustre and colour as in hornblende. In many cases it is very difficult to distinguish this mineral from amphibole; the student should then speak of the mineral as pyroxene *or* amphibole.

OLIVINE.—Composition, silicates of iron and magnesia. Crystallises in the trimetric system. Cleavage imperfect, and therefore breaks with a conchoidal fracture. H = 6. Lustre vitreous. Colour usually olive-green. It often occurs in grains in igneous rocks, and resembles quartz; but as its usual colour is very unusual in quartz, it may be practically dis-

[1] *Augite* is a common form in igneous rocks.

tinguished by its colour, and, as already stated, by its occurrence in basic or ultrabasic rocks.

APATITE.—Composition, phosphate of lime, with some chloride or fluoride of lime. Crystallises in the hexagonal system. H = 5. Colourless and glassy, or opaque and coloured green or pink. Occurs in small crystals in many igneous rocks, and in large crystals in certain metamorphic rocks, which are also probably of igneous origin. Non-crystalline phosphates of lime are found in deposits, and are important to the agricultural student. These phosphates are most readily detected by a chemical test, solutions giving a deep yellow precipitate with a solution of ammonium molybdate.

MAGNETITE is simply mentioned here as one of the ore-constituents of igneous rocks, and need not be described. These ore-constituents usually occur in exceedingly small crystals in the common igneous rocks which contain them, and can seldom be detected with the unaided eye, or even with a lens.

We may now proceed to consider those minerals of importance to us which are seldom or never found as original constituents of igneous rocks.

ROCK-SALT.—Composition, chloride of sodium. Crystallises in the cubic system. Soluble in water. Recognised by its taste. H = 2 (can be scratched with the finger-nail). Occurs in deposits, often associated with gypsum and beds of sandstone and mudstone; frequently coloured red. The salt itself (colourless when pure) may also be coloured by impurities, and is often yellow or red.

GYPSUM.—Composition, hydrated sulphate of lime. Crystallises in the monoclinic system. Readily cleaves, furnishing flexible, inelastic flakes. H = 1·5–2 (can be scratched with the finger-nail). Lustre satiny. Transparent to opaque. White, or coloured by various impurities. Often occurs in deposits, frequently in fibrous masses. Anhydrous sulphate of lime is known as *anhydrite*, which crystallises in the trimetric system and has a hardness of 2·5–3·5.

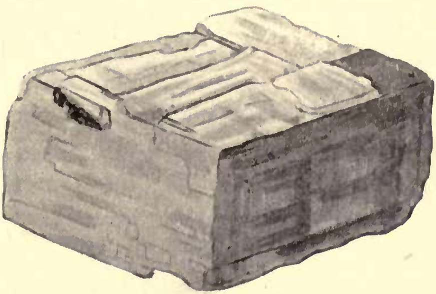


FIG. 17.

RHOMB OF CALCITE.

Showing lines and faces of cleavage.

CALCITE.—Composition, carbonate of lime ($CaCo_3$). Crystallises in the hexagonal system. Perfect cleavage into rhombohedra (Fig. 17). H = 3 (can be easily scratched with a knife). Lustre pearly. Effervesces with dilute acids. Colour white when pure. Transparent to opaque.

Occurs as a secondary constituent in igneous rocks; also in mineral veins. Carbonate of lime is widely distributed in beds in the crystalline or amorphous condition..

SERPENTINE.—Composition, hydrated silicate of magnesia. Will be considered as a rock.

IRON PYRITES.—Composition, iron bisulphide (FeS_2). Crystallises in the cubic system, generally as cubes, often as octahedra. Faces of the cubes often striated. H = 6–6·5. Lustre metallic. Colour brass-yellow. Rarely found as an original constituent of igneous rocks. Frequently found in sediments as crystals, or radiating fibrous aggregates.

CHAPTER IV

THE IGNEOUS ROCKS

THE rocks mentioned in the table (p. 22) will be described here with those variations which are of importance. The rocks will be described in the order of their acidity, and in each division the plutonic rocks will be first considered, and the volcanic rocks last.

I. ACID ROCKS (65–80 % SiO_2)

(1) PLUTONIC

GRANITE.—A holocrystalline rock consisting of quartz, orthoclase felspar (often, also, some plagioclase), and a ferro-magnesian mineral, usually mica or amphibole. The rock is coarse-grained to fine-grained, but the individual grains are easily detected by the eye. The mica usually crystallises first (and hence often presents definite crystal outlines), then the orthoclase, and lastly the quartz, which thus occupies interstices between the other minerals. The mica may be muscovite or biotite, and both are sometimes present. The felspar is usually pink or white. Porphyritic crystals of felspar frequently occur.

The best-known British granites are those of

Devon and Cornwall, including the Dartmoor granite, the granites of Eskdale and Shap, in the Lake District, the hornblendic granite of Charnwood, in Leicestershire, that of the Cheviot Hills, those of Aberdeen, Mull, and Crifell in Scotland, and of Donegal, the Mourne Mountains, Dublin, Wicklow, and Wexford in Ireland.

(2) INTRUSIVE

QUARTZ-PORPHYRY.—These rocks consist of porphyritic crystals of quartz and felspar embedded in a ground-mass of fine-grained character composed of the same crystals. A ferro-magnesian constituent, as mica or hornblende, is usually present. The term elvanite is sometimes applied to these rocks. Quartz-porphyries are often found as dykes or sills in the neighbourhood of granitic masses, though they may, of course, occur when granite is not apparent at the surface.

(3) VOLCANIC

RHYOLITE.—Rhyolites may or may not contain porphyritic crystals of quartz and felspar. The ground-mass usually consists of microlites of felspar, though glass is often present. The rocks often exhibit flow-structures, such as banding, and perlitic and sphærulitic structures are frequently present.

FELSITE.—Many of the ancient rhyolitic rocks of Britain have undergone a change known as *devitrification*, resulting in a more crystalline condition of the ground-mass. These rocks are frequently spoken of as *felsites* (a term which has been used with somewhat different significations). The British felsites are either ancient lavas, or else they form dykes and sills which are intrusive into the surrounding rocks. They are found in many localities, among which we may specially note the ancient volcanic regions of Wales, the Lake District, and the centre of Scotland.

OBSIDIAN.—A natural glass, breaking with a conchoidal fracture; usually black. It always contains crystallites. It is found in abundance in some modern volcanic districts, but not in Britain.

PUMICE is a glass in which the vesicular structure is especially well developed.

II. INTERMEDIATE ROCKS

A. SUB-ACID

(1) PLUTONIC

SYENITE differs from granite in the absence (or rarity) of quartz. It consists of orthoclase (often with some plagioclase) and a ferro-magnesian mineral, as amphibole or pyroxene, more rarely mica. Syenites are not abundant in Britain.

(2) INTRUSIVE

QUARTZLESS PORPHYRY bears the same relationship to syenite that quartz-porphyry bears to granite, and needs no further notice here.

(3) VOLCANIC

TRACHYTE.—The trachytes (so called from the rough feel of many of these rocks) are to syenites what rhyolites are to granites. They are consequently less acid than the rhyolites. They occur as lavas, but are practically absent from Britain. Porphyritic felspars often occur in them, especially a glassy variety of orthoclase felspar, termed *sanidine*.

B. SUB-BASIC

(1) PLUTONIC

DIORITE consists of plagioclase felspar and amphibole, though pyroxene is sometimes found, when the rocks approach to gabbro in composition. The rock is usually coarse-grained, or fairly so. In some varieties of diorite free quartz is found, forming an exception to the rule that it is characteristic of the acid rocks. Diorites occur in England in Warwickshire, Leicestershire, and Cumberland; in Wales in Anglesey and Carnarvonshire; also in the Highlands of Scotland.

(2) INTRUSIVE

PORPHYRITE.—This name has been used in many different senses. It would perhaps be better to use the term diorite-porphyrite for the rock placed in this division. The rock consists of a purely crystalline ground-mass of plagioclase felspar and a ferro-magnesian mineral, usually amphibole or pyroxene, and often contains porphyritic crystals of plagioclase.

Porphyrites are frequent among the lavas and dykes of the old red sandstone rocks of Scotland.

(3) VOLCANIC

ANDESITE.—The andesites consist of a ground-mass of plagioclase felspar, often in lath-shaped crystals, and frequently associated with a ferro-magnesian mineral. Porphyritic crystals are often found. They may be formed of plagioclase and pyroxene or amphibole. Quartz is present in some andesites.

Andesites are found among many of the ancient volcanic rocks of Britain, *e.g.* North Wales, the Lake District, and Scotland.

III. BASIC ROCKS

(1) PLUTONIC

GABBRO.—A holocrystalline rock, composed of plagioclase felspar and pyroxene. The rock is often very coarsely crystalline, the pyroxenic constituent being specially noticeable. The gabbros pass into diorites on the one hand, and into ultrabasic rocks on the other hand. The latter passage is marked by the appearance of olivine as a constituent mineral. Typical gabbros are found in the Lizard district of Cornwall, at Carrock Fell in Cumberland, in Anglesey and Carnarvonshire, in many parts of Scotland, especially in some of the western isles, as Skye and Mull, and in the Carlingford district of Ireland.

(2) INTRUSIVE

DIABASE is an intrusive rock, which, containing the same minerals as gabbro, is less coarsely crystalline than that rock. The felspars of diabase frequently possess their proper crystal outlines; this is not often the case with typical gabbro. As in gabbro, so in diabase, olivine may occur in addition to the plagioclase and pyroxenic constituents.

Many sills and dykes in North Wales consist of diabase. It also occurs in the Lake District. Olivine diabases are found in the South of Scotland. The well-known "whin-sill" of the northern counties of England is a quartz-diabase.

(3) VOLCANIC

DOLERITE and BASALT.—These rocks consist of plagioclase, pyroxene, and often olivine. Some writers consider that the term basalt should only be applied to those rocks in which olivine is present. Iron ores are found in greater or less abundance. The dolerites are fairly coarse-grained, while basalts are fine-grained to compact. The plagioclase usually occurs in lath-shaped crystals. The rocks are black when fresh, but when decomposed often assume various shades of green, orange, and brown. Ancient dolerites and basalts are found in many parts of Britain. The most extensive development is in Scotland and Antrim, where great masses of lava of the Tertiary Age occur, and are associated with numberless dykes and sills.

TACHYLITE is the basic glassy rock which has a chemical composition similar to basalt. It often occurs as selvages to basaltic dykes.

IV. ULTRABASIC ROCKS

A great variety of ultrabasic rocks are known, most of which are far from common. The best-known is serpentine, which will alone be noticed here.

SERPENTINE is a rock which, in most cases, originally consisted of olivine as the dominant mineral, associated with a ferro-magnesian mineral and an ore. Olivine is very liable to undergo alteration, which causes marked physical change in addition to the chemical change. The latter consists in the conversion of silicate of iron into a hydrate, which frequently remains in the rock as a colouring matter. The silicate of magnesia is left, and forms the bulk of the rock, which is now soft and earthy, with a soapy feel. The colour varies, different shades of red and green predominating. The various colours often occur in spots and streaks, causing the rocks to possess markings somewhat recalling those on the skin of the serpent, from which, indeed, the rock takes its name.

The best-known British serpentines are those of the Lizard district and of the South of Scotland.

Serpentine has been noticed here as being the commonest representative of the ultrabasic rocks. Strictly speaking, it is a metamorphic igneous rock, and might have been considered with other metamorphic rocks, which will require special treatment by themselves.

FRAGMENTAL VOLCANIC ROCKS

As the fragmental rocks which are ejected from volcanoes in the solid condition, in pieces of varying size, and collect upon the flanks in layers, possess the same general composition as the igneous rocks from which they are derived, and therefore yield similar substances to the soil, they are most conveniently treated here. These rocks are spoken of collectively as *pyroclastic* rocks, as the constituent fragments are broken by the agency of heat, and not by the weather or moving water, as in the case of the component particles of the ordinary sediments. The pyroclastic rocks, like ordinary igneous rocks, may be of acid, intermediate, or basic composition. They may contain quartz, though the dominant fragments consist of felspar and ferro-magnesian minerals. Many of the fragments are *lapilli*[1] of lava, which may be either crystalline or glassy. The fragments vary in size. Large fragments are usually angular, and are embedded in a ground-mass of finer material. The pyroclastic rocks which contain these angular fragments are known as *volcanic breccias*, or, in one word, as *agglomerates*.

The particles composing the ground-mass of the rock may also vary in size. At a distance from the volcanic vents the very finest dust may accumulate. Should it fall upon the sea-floor, it may enclose the remains of varied organisms, and become *fossiliferous*. The finer pyroclastic rocks are usually spoken of as volcanic *ashes*. Many names are applied to varieties of ash, but it is not necessary for us to consider them.

[1] *i.e.* little stones.

CHAPTER V

THE SEDIMENTARY ROCKS

THE sedimentary rocks may be classified according to their method of formation, in which case they can be grouped as—

(1) Mechanically formed,
(2) Chemically formed,
(3) Organically formed;

or a classification may be based upon their composition. The latter mode of grouping is most convenient to us in the present stage of our inquiry. The following divisions of the sediments will be adopted:—

Arenaceous rocks, *e.g.* sandstones, grits.
Argillaceous rocks, *e.g.* mudstones.
Calcareous rocks, *e.g.* limestones.
Siliceous rocks, *e.g.* flint and chert.
Carbonaceous rocks, *e.g.* coal.
Precipitated salts, *e.g.* rock-salt and gypsum.

Two objections may be raised to this classification. In the first place, it is clear that a rock may consist of a mixture of the different constituents in various proportions; *e.g.* we may have calcareous sandstones.

In these cases the rock may be considered under the head of its more important constituent, unless its constituents are of equal importance, when it must be regarded as intermediate between the rocks of two groups. The other objection is more serious, namely, that the classification is based partly on physical differences and partly on differences of chemical composition. For instance, a mudstone may have the same composition as a sandstone, but be placed in the argillaceous division on account of the small size of its component particles; while a limestone may be composed of worn grains of carbonate of lime, in which case it is physically a sandstone, though chemically a limestone.

The classification is, in fact, merely provisional, but for our purposes it will be found sufficient.

I. ARENACEOUS ROCKS

SAND, SANDSTONE.—A rock consisting of grains varying in size and shape. If the grains are very small, the rock passes into a mud; and if large, into a gravel or conglomerate. The variations in shape depend on the conditions of formation. Desert sands are often formed of rounded grains; lake sands, river sands, and sea sands of angular grains.

The composition of the grains also varies. Chips of minerals of all kinds may enter into the composition of sand. Quartz is the commonest component, and many sands are pure, or nearly pure, quartz sands. If much felspar be mixed with the sand, it is termed *arkose sand*. When mica is found in spangles the rock is a micaceous sand. Pyroxene, amphibole, and other minerals are frequent.

In chalk districts flint sand is often found; in volcanic districts volcanic sand, composed of lapilli of volcanic rock, occurs. Coral sand belongs to the calcareous division.

Some sands contain grains of a green mineral substance known as glauconite, which also occurs in mud and calcareous rocks. It is of variable composition, consisting chiefly of silicates of alumina and iron.

The cementing material of sandstones may vary. Silica forms a common cement. If the grains are united by carbonate of lime, the rock becomes a calcareous sandstone. Various compounds of iron occur as cements. At a considerable depth carbonate of iron binds the rock grains together. The rock then has a grey or blue-grey colour. At or near the surface oxides or hydrates of iron are frequently found as cements. The former often give a red colour to sandstone, and the latter impart various hues of yellow, orange, or brown.

Conglomerate.—A rock consisting of pebbles usually accompanied by smaller grains, which fill the interstices between the pebbles. The smaller grains are very frequently sand, but the pebbles may also be embedded in argillaceous or calcareous materials. The pebbles are more or less rounded, and sometimes approach the spherical form. They may be composed of any kind of rock, and in many conglomerates rocks of various kinds contribute to the pebbles. As quartz is very durable, pebbles of this substance are very frequent, and if the majority of pebbles are quartzose, the rock is a quartz-conglomerate. The cements of conglomerates are similar to those of sandstones.

BRECCIA is a rock which differs from a conglomerate in possessing angular instead of rounded pebbles. Breccias may be formed as beaches on calm sea-coasts. Bone breccias consist of fragments of bone, bits of limestone, and other materials which have accumulated upon the floors of caverns in limestone rocks.

II. ARGILLACEOUS ROCKS

CLAY, MUDSTONE.—As the result of the decomposition of felspars, a pure silicate of alumina may be produced, known as *kaolin* or *china clay*, and the term clay is sometimes used for rocks consisting essentially of silicate of alumina, while very fine-grained sediments of varying composition are known as *muds*, or when consolidated, as *mudstones*. The term *clay* is, however, generally applied to such rocks, which consist of very minute chips of various minerals, usually mixed with a considerable proportion of silicate of alumina, the latter being due to the decomposition of minerals containing aluminous silicates associated with other silicates. Clays may be consolidated by pressure only.

Many clays contain a certain proportion of alkalies, especially potash, which, though small in quantity, is of great importance to the agriculturist. The clays beneath many coal-seams, known as *underclays*, contain a very small amount of alkali as compared with other clays; hence they are much less fusible than ordinary clays, and are adapted for resisting great heat. Such clays are spoken of as *fire-clays.*

Clays are often coloured by the same materials as sands. Red clays coloured by peroxide of iron are sometimes termed red *marls*, though the term marl is, strictly speaking, used of a rock consisting of clay and some calcareous matter.

SHALE is a rock which is *laminated;* that is, it is marked by the possession of a number of bedding-planes, separated from each other by very thin layers of sediment. The rock accordingly splits into thin pieces, and is very readily acted upon by the weather. Most shales are clay-rocks, though sandstone shales are by no means uncommon.

SLATE is a rock which is, strictly speaking, a metamorphic rock. It is a clay which does not split along the bedding-planes, but along planes which are due to lateral pressure having acted on the rock subsequently to its formation. It is therefore much more compacted than an ordinary clay. The planes of fissility may lie at any angle to the planes of original deposit. These *cleavage-planes*, as they are termed, are usually at a high angle, or actually vertical, though not always so.

III. CALCAREOUS ROCKS

Calcareous rocks consist essentially of carbonate of lime, or of carbonates of lime and magnesia, the latter being less common than the former.

LIMESTONE.—A term employed for any rock which is mainly or entirely composed of carbonate of lime, which may exist in the rock in a crystalline or non-crystalline (amorphous) condition. These limestones may be formed by chemical precipitation or by organic agency, the latter being more common among the sedimentary rocks. The principal lime-forming organisms are: among plants, various calcareous algae; among animals, the foraminifera, corals, crinoids or sea-lilies, crustacea, and mollusca. Some limestones are formed exclusively, or nearly exclusively, of one kind of organism, while many consist of a mixture of the hard parts of various organisms. These hard parts are often preserved in the rock, but in many limestones the original organic structure of the component organisms is largely or entirely obliterated.

There are many varieties of limestone, differing from one another in mode of formation or in their characters, of which we may briefly notice the principal.

CALCAREOUS TUFA.—A chemical precipitate of carbonate of lime deposited from springs or in inland lakes which have no outlet. It is often markedly crystalline. The pendent masses on the roofs of caverns are termed *stalactites*, and the masses deposited on the floor of these caverns are known as *stalagmite*.

CHALK is an earthy, amorphous limestone composed of tests, or fragments of tests, of various organisms.

OOLITE.—A limestone composed largely of spherical or elliptical grains about the size of a pin's head and resembling fishes' roe; hence the name. When the grains are larger and about the size of a pea, the rock is known as *pisolite*. The "grains" of pisolite are really the hard parts of lowly organisms.

MAGNESIAN LIMESTONE is a mixture of carbonates of lime and magnesia in varying proportions. It is sometimes termed dolomite, though this term should, properly speaking, be used of the mineral in which these two carbonates are found in definite proportions. The rock is usually of a cream-yellow colour, and is frequently marked by numbers of irregular hollows, which give it a rough, cindery appearance.

CALCAREOUS MARL.—A mixture of clay and carbonate of lime in varying proportions. The carbonate of lime is often found in the form of shells of organisms, when the deposit is known as shell-marl. Shell-marls of this nature are frequently found beneath peat-mosses, which occupy the sites of vanished fresh-water lakes.

IV. SILICEOUS ROCKS

SILICEOUS EARTHS.—Various recent or comparatively recent deposits of a siliceous nature, and of incoherent character, may be spoken of under this name. They usually consist of the hard parts of plants known as diatoms, or of the tests of minute animals termed radiolaria.

FLINT, CHERT.—Flint consists of silica formed partly by organic agency and partly by chemical action, associated with calcareous rocks. It may occur in nodules, horizontal bands, or vertical tabular masses. The best-known flint deposits are those of the chalk, but flint being comparatively indestructible, fragments of it compose the bulk of many gravels in a chalk district.

Chert has a similar composition, nature, and origin to flint. It is usually less pure than flint. It is found associated with many British limestones, and also with other sediments.

V. CARBONACEOUS ROCKS

PEAT will be considered under the head of soils.

LIGNITE.—A rock consisting of organic matter containing carbon, hydrogen, oxygen, and nitrogen in the following proportions: carbon, 67–68 %; hydrogen, 5·5 %; oxygen and nitrogen, 26·5–27·5 %, mixed with a varying quantity of inorganic *ash*. It has a woody texture, and exhibits vegetable structure.

BROWN COAL differs from lignite in the absence of marked vegetable structure throughout the rock; it also contains about 4–5% more carbon, with a corresponding decrease in the proportion of oxygen and nitrogen, the hydrogen remaining as before.

Lignites and brown coals are chiefly found in Tertiary rocks. They are not common in Britain, though they occur in the island of Mull and at Bovey Tracy in Devonshire.

COAL.—A popular term which has been adopted in rock nomenclature for a black rock of somewhat similar origin to lignite and brown coal, though it has undergone greater alteration than those rocks, with loss of more of its volatile constituents. The amount of hydrogen does not differ in a marked degree in typical coals, varying from about 5 to 5·5%. The other constituents vary considerably, the lowest percentage of carbon being about 80, with oxygen and nitrogen a little below 15%, while the highest percentage of carbon is about 88, with less than 7% of oxygen and nitrogen.

The best-known coals of this and other countries occur in what are known as the Carboniferous Rocks, and the organic matter of those coals is largely composed of the remains of lycopodiaceous plants.

ANTHRACITE or STONE COAL is best known from South Wales and Pennsylvania. In this rock the hydrogen may be below 2%, the oxygen and nitrogen from 1 to 3 %, and the carbon from 93 to over 97 %.

VI. PRECIPITATED SALTS

Various chemical precipitates are formed in the waters of inland seas having no connection with the open oceans, as in the Great Salt Lake of Utah, and in many of the sheets of water of the Aralo-Caspian Basin. They are also found in the ancient sediments under conditions which point to their formation in similar salt lakes of past times. In desert regions salts are also formed in hollows where water does not permanently accumulate. These substances are in many cases useful as fertilisers, and as they will be again considered in the chapter which treats of natural manures, we need not treat of them more fully here. They consist chiefly of various chlorides, carbonates, sulphates, and nitrates, especially of the alkalies and alkaline earths.

CHAPTER VI

THE DIVISIONAL PLANES OF ROCKS

TO the student of geology the study of the divisional planes of rocks is of prime importance. The theoretical geologist utilises some of these planes in the establishment of the sequence of geological events. To the student of geological economics they are of great practical value, as assisting in quarrying, mining, water-finding, and agricultural operations.

Some of these planes are limited to the stratified rocks, while others affect both stratified and igneous rocks alike. The principal divisional planes are termed *stratification*-planes, *joint*-planes, *fault*-planes, *cleavage*-planes, and *foliation*-planes. The first-named are those which are confined to stratified rocks, and they are the most important of all the planes, and will be considered first.

I. PLANES OF STRATIFICATION AND LAMINATION

The stratified rocks were laid down upon the earth's surface, and especially upon the floors of water areas. These floors, on a large scale, approach horizontality, and when highly inclined locally the deposits abut against the slopes. At any particular time the surface of a deposit will therefore tend to be a horizontal plane. As planes of stratification mark such surfaces under particular conditions they tend to have horizontal surfaces, though subsequently to their formation they may, and often do, become inclined at various angles. A plane of stratification usually is, but need not necessarily be, a plane of discontinuity. Imagine a flat tract of sea-floor which is receiving a deposit of sand, and that this sand accumulates to a certain thickness, say two feet, when the supply of sand is replaced by one of clay, which is laid down on the top of the sand, and that after a foot of clay has been deposited, sand is once more brought to the tract and laid down on the top of the clay. The accumulation of clay is spoken of as a *bed* or *stratum*, and each of the accumulations of sand also forms a bed. The divisional planes separating the clay from the sands above and below are *planes of stratification* or *bedding-planes*. If the supply of clay suddenly succeeds the supply of sand, there may be complete coherence between the sand-bed and the clay-bed. A bedding-plane of this character, which does not form a plane of discontinuity, can only separate two dissimilar sediments. If the change of sediment occurs after a pause, the lower bed may be to some extent consolidated before the deposition of the upper bed upon it. In this case there may be absence of coherence between the two beds, and portions of one bed may be readily separable from the other along the bedding-plane. A bedding-plane which forms an actual plane of discontinuity may separate dissimilar strata, or it may separate two precisely similar strata, as two beds of sand.

In Fig. 18 five beds are exhibited, numbered 1–5, separated from each other by four planes of stratification.

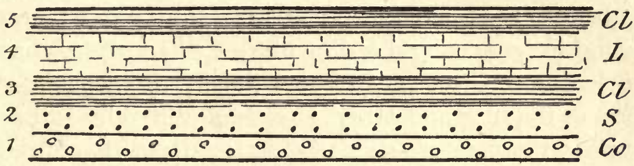


FIG. 18.

SECTION OF PLANES OF STRATIFICATION.

Cl=Clay. *L*=Limestone. *S*=Sandstone. *Co*=Conglomerate.

The conventional signs used in this section are frequently used for the various kinds of sediment which are exhibited, and the student should remember them.

Though the upper and lower surfaces of the beds are, in most cases, practically parallel, owing to the great horizontal extent of a bed and its small vertical thickness, the planes eventually approach each other as the bed *thins out*, and accordingly beds are really lenticular deposits, in which the length of the lenticle is usually a very large multiple of its thickness. When the bedding-planes are very close together, usually several in the thickness of an inch, they are spoken as planes of *lamination*. Laminated beds are termed shales, and, as already stated, shales are chiefly laminated clays, though we also meet with laminated sandstones. When the beds are somewhat thicker than laminae, the thin beds are spoken of as *flags;* flags are usually arenaceous or calcareous. In each case they may be mixed with a considerable amount of clay.

II. JOINT-PLANES

Joint-planes, unlike planes of stratification, are found in igneous and sedimentary rocks. In igneous rocks some joints were formed during the consolidation of the rock and others afterwards; in sedimentary rocks all joints were formed after the deposition of the rocks. Joints differ in character and also in origin, but in all cases they form planes of discontinuity, along which the rocks may be split. It is true that at great depths the discontinuity is in many cases not apparent, as the sides of the joints are closely pressed together; near the surface, owing especially to weather action, the joint-planes are usually very apparent, and may even occur as actual fissures.

In describing the variations among joints, it will be convenient to consider, at the outset, the joints found in igneous rocks, and then to refer to those which traverse the rocks of sedimentary origin.

Of joints formed during the consolidation of igneous rocks, columnar joints are among the most remarkable. The well-known columns of basalt on Staffa and at the Giant's Causeway are caused by joint-planes. These columns usually run at right angles to the surfaces along which the rock commenced to cool, and therefore to contract. In a rock of uniform character they tend to become symmetrical, and to assume the hexagonal outline, for there are only three regular figures which can be placed together without interstices occurring between them, namely, the equilateral triangle, square, and hexagon, and of these the equilateral triangle has the greatest periphery in proportion to the area and the hexagon least; consequently it is easier for the rock to break into columns of hexagonal than of square or equilateral triangular outlines. In other cases the rock tends to break into plates along joints which run generally parallel to the surfaces of cooling. This *platy-jointing* is often useful as rendering the rock easy to break into small pieces for road-metal.

Many igneous rocks are traversed by systems of joints, in which the joints of one system retain general parallelism, often for considerable distances. The rocks may break into cubical, rectangular, rhomboidal, or prismatic pieces along these joint-planes. As joints due to contraction of the rock while cooling possess, as we have already seen, a tendency to break into hexagonal columns, the absence of hexagonal boundaries to the surfaces in the case of cubical and other joints indicates that these were not formed by cooling, but subsequently to the consolidation of the rock. Many were, no doubt, due to earth-movements acting upon the solid rock. When a rock is stretched, it may yield by rearrangement of the component particles, or it may break, producing joints, and as no planes of discontinuity are formed by deposit in the case of igneous rocks, it requires three sets of planes to allow the stretched rock to adapt itself to the new conditions.

The joints which traverse sedimentary rocks require somewhat fuller consideration, from their very great importance.

Sediments, like igneous rocks, undergo contraction, not from cooling, however, but by loss of moisture when drying, and joints are frequently produced in this way, which may assume the columnar form, though the columns are rarely as regular as those of igneous rocks. The greater number of important regular joints in sediments are generally considered to be due to earth-movements. In the case of the sediments one set of planes is already in existence, viz. the bedding-planes, and two sets only are required to relieve tension. Accordingly the dominant joints of sediments, or *master-joints*, as they are termed, are usually found forming two sets, which tend to occur in planes lying vertically to the bedding-planes and trending in directions at right angles to one another. When strata are inclined, one set of joints is often found trending in the same direction as that in which the beds plunge down into the earth. This direction, as will be more fully explained eventually, is spoken of as the direction of *dip* of the rock, and these joints are therefore spoken of as *dip-joints*, while the direction at right angles to the direction of dip is spoken of as the direction of *strike* of the rock, and joints which trend in that direction are therefore termed *strike-joints*. When strata are quarried the back of the quarry is often determined by one set of joints, frequently the strike-joints, and the ends of the quarry by the other set, frequently the dip-joints. In Fig. 19 the surfaces of a quarry are shown, and they are seen to run parallel to the two sets of master-joints.

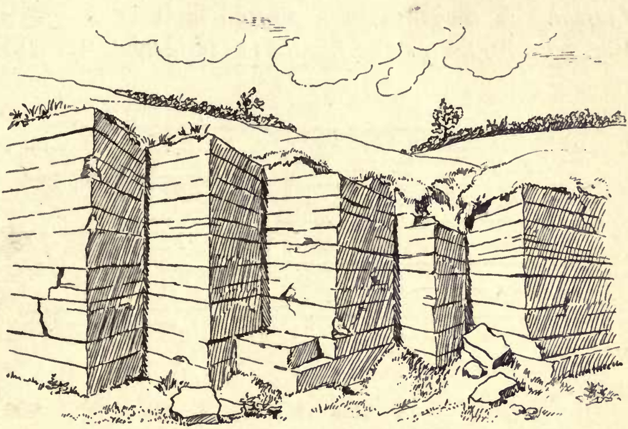


FIG. 19.

QUARRY SHOWING STONES REMOVED ALONG JOINTS.

The nearly horizontal lines indicate bedding-planes, and the vertical faces joint-planes.

In addition to these master-joints, many minor joints, of more or less irregular trend, often traverse the sediments, and are useful for facilitating the fracture of the rock into small pieces.

Just as these joints are utilised by man in his quarrying operations, so, as will be more fully shown in the next section, Nature makes use of them in carrying out her quarrying operations.

III. FAULT-PLANES

Should the beds be displaced on one or both sides of a joint, so that the edges of each bed do not join at the fissure, the beds are said to be *faulted.* A diagram of a simple fault is shown in Fig. 20. So far as the fissure is concerned, the fault

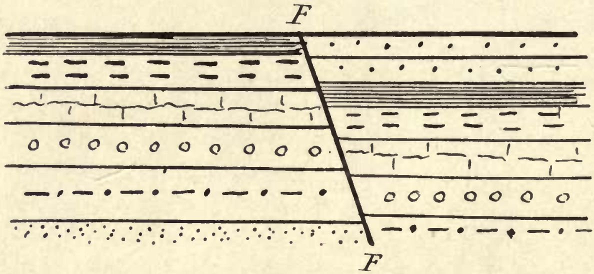


FIG. 20.

SECTION OF FAULT.

F F = Fissure.

does not differ in any marked respect from a joint-plane, save for certain changes which occur along the plane of fissure. The movement of one cheek of the fissure along the other often gives rise to parallel flutings of the sides, which may also be polished, and may receive a film of deposit of mineral matter upon them. Such flutings are spoken of as *slickensides.* Not only is the rock bordering the main fissure slickensided, but frequently also the rock bordering neighbouring joint-planes. Should the fissure be crooked, convex parts of the rock may abut against each other, as shown in Fig. 21.

Fragments of the rock are frequently broken off during the movement and wedged in the open parts of the fissure. These fragments are usually angular. As the result of the considerable pressure of cheek against cheek, much of the material may be ground to powder, and this compressed powder may yield a fine base in which the fragments of the broken

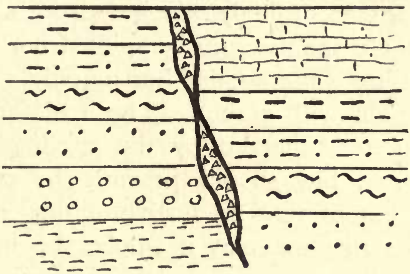


FIG. 21.

SECTION OF FAULT.

Showing irregular fissure filled with fault-breccia (the latter represented by triangles).

rock are embedded. A rock is thus produced which is called a *fault-breccia.*

By infiltration of various metallic ores along fault-planes, ordinary metalliferous veins are produced. Their consideration does not directly concern us, though it is useful to know that these ores may be found accompanying fault-breccias, though the larger proportion of fault-breccias contain no metallic ores.

The variations in the characters of faults, the nomenclature in use with reference to faults, and the manner in which strata are affected by faults, will be considered in a later section under the head of Geological Maps.

IV. CLEAVAGE-PLANES

In areas where rocks have undergone great lateral pressure, a considerable rearrangement of the rock-masses results from the pressure. These masses are compelled to occupy less room in a horizontal direction, and are accordingly elongated in a vertical direction should the pressure be applied horizontally. (If the pressure is not applied horizontally, a slightly different result will ensue). The rocks are first thrown into folds marked by the curving of their bedding-planes, but should pressure be continued to such an extent that no further folding can take place in the rock-mass as a whole, the individual particles of the rock-mass yield, becoming compressed in the direction in which pressure is applied and elongated in the opposite direction, so that all the longer axes of the particles are now arranged in the latter direction, and the length of those axes is increased by pressure, while that of the shorter axes is diminished. This is illustrated by Fig. 22.

As the particles of clay yield most easily to lateral pressure, rearrangement and deformation of the particles take place more frequently in clays than in other rocks, though they are not necessarily confined to them. Rocks which have undergone this change are known as *slates*, and when clay is thus affected, the rock is spoken of as clay-slate, though the term slate as generally used implies clay-slate. The structure is known as *cleavage.* A cleaved rock may be split into thin slabs, the faces of which run in the direction of the elongated axes of the particles. A cleaved rock does not necessarily possess planes of discontinuity due to cleavage, though as the result of weather-action cleavage-planes may become planes of discontinuity. Every plane separating two particles is practically a plane of weakness, and it results from this that, had we sufficiently delicate instruments, we

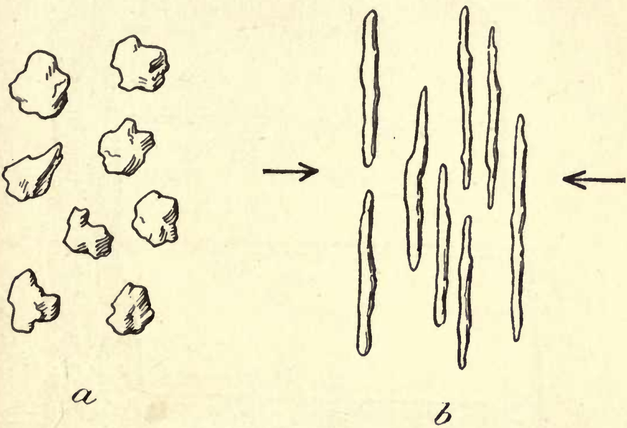


FIG. 22.
PARTICLES.
a = Before cleavage. *b* = After cleavage.
Arrows show direction of pressure.

might continue splitting a slate in the direction of the cleavage-planes until we had reduced it to its component particles. In this respect cleavage differs from jointing. Jointed rocks may be split into very fine slabs if the joints are sufficiently close, but the rock between two contiguous joints possesses no tendency to split parallel to those joints more readily than in another direction.

If thin beds of grit are intercalated between the beds of clay which have become cleaved, the grit may escape cleavage, and is often puckered up between the slate-bands, as seen in Fig. 23.

Some rocks which are used for roofing purposes

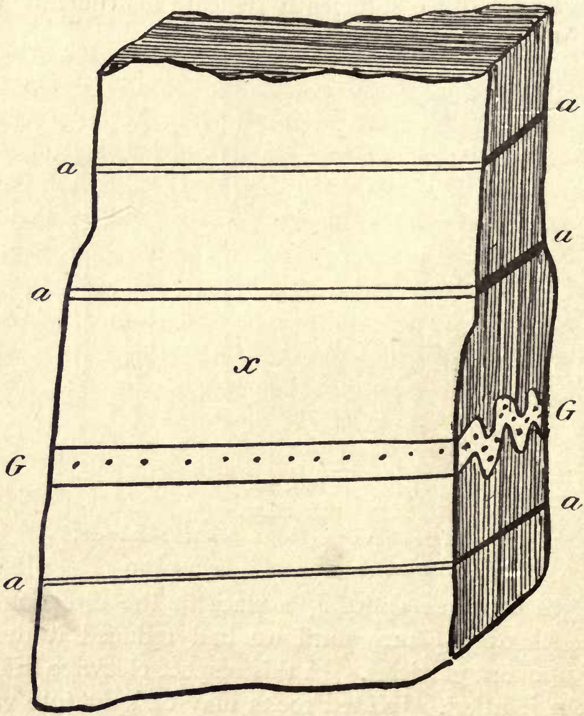


FIG. 23.

BLOCK OF SLATE.

x = Cleavage-face. *a a* = Original bedding. *G G* = Grit-band.

The finer lines on the right-hand side and on the top indicate cleavage-planes.

are spoken of as slates, though they are not cleaved, *e.g.* the Stonesfield 'slate' of Oxfordshire and the Collyweston 'slate' of Northamptonshire.

V. FOLIATION-PLANES

In many regions, as in the Scottish Highlands, extensive areas are occupied by crystalline rocks, which split into thin layers along planes which generally run parallel with the longer axes of the component crystals. These planes may be straight, but they are frequently crumpled and twisted in a marked degree. Such rocks are known as *schists*, or when more coarsely crystalline, as *gneisses*, and the planes are spoken of as *foliation-planes*. The minerals may be, and often are, arranged so that one layer or *folium* consists of particles of one kind of mineral, as shown in Fig. 24, which represents a piece of schist com-

FIG. 24.
FOLIATED ROCK.

posed of folia of quartz and mica. The origin of these schistose rocks is still to some extent obscure, but, apart from this crystalline character of the rock, it may be noted that the divisional planes may be original planes of bedding, or may be cleavage-planes. As many slates also possess a finely crystalline structure, there is no difference except one of degree between these slates and schists which possess foliation parallel to cleavage. The composition of schists depends to a considerable extent upon the composition of the rock which has become foliated; this will be more fully considered in the following chapter.

CHAPTER VII

ON CERTAIN CHANGES WHICH ROCKS HAVE UNDERGONE SINCE THEIR FORMATION

WHEN dividing the rocks into the igneous and sedimentary groups, it was noted that a third group was sometimes introduced with the title of metamorphic rocks. This title implies that rocks to which it is applicable have been changed since their formation. As all rocks undergo some kind of change, it is impossible to draw a hard line between metamorphic rocks and those in which the changes are so slight that the term is not usually applied to them.

Some of the changes which are metamorphic in the ordinary sense of the term have already been briefly noticed, *e.g.* the production of serpentine and the formation of schists. In the present chapter reference will be made to such changes of rocks, whether metamorphic or not, in the ordinary sense of the term, as are of importance to the student of agriculture.

I. METAMORPHIC ROCKS

Rocks may be metamorphosed by the action of water, heat, or pressure, or by the combined action of two of these or of all three.

The action of water tends to remove some materials, to alter existing materials in the rock, and to introduce new materials. The changes produced by water, which are of special importance to the agriculturist, are not those which give rise to what are commonly known as metamorphic rocks, and they will be considered in a subsequent section under the head of Weathering Action.

The action of heat is well seen in the rocks around intrusive rocks. The intrusive rocks often harden the surrounding rocks, and may cause the development of new minerals in them. Granite, for instance, often causes marked metamorphism in its vicinity; should the granite occur in a roughly circular mass, there will be a ring of altered rocks around it, as seen in Fig. 25. This ring of altered rocks is spoken of as an *aureole.* The changes which take place in the rocks of this aureole often render them less resistant to the weather, and the aureole may therefore furnish useful materials for road-metal.

The origin of the crystalline schists, which are frequently developed over wide areas, is, as has been observed, still in a considerable degree obscure. That pressure and heat have both played a part in their formation is clear, and no doubt the presence of water has assisted the processes. These crystalline schists (with the accompanying gneisses) may originate from both igneous and sedimentary rocks. The igneous rocks often give rise to coarse gneisses, which, apart from their parallel structure, need not differ in a very marked degree from the original rock, though in many cases considerable chemical changes do take place. The sediments become markedly crystalline, and new material may be introduced. Both the physical and chemical changes which these schistose rocks have undergone play an important part in influencing the action of weathering and other agents

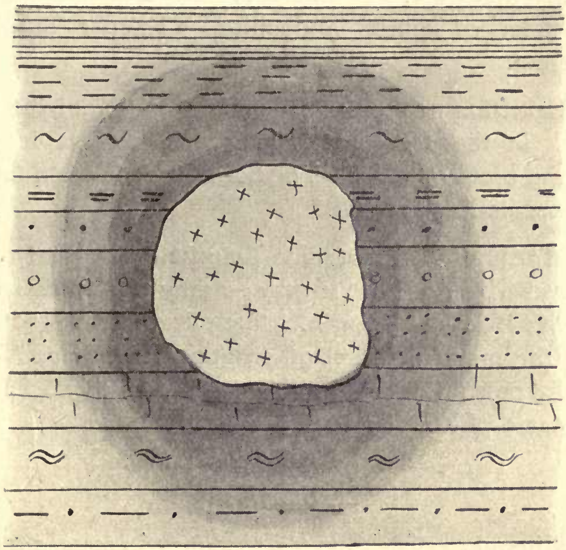


FIG. 25.

PLAN OF AUREOLE OF METAMORPHISM AROUND IGNEOUS ROCK.

Igneous rock marked by crosses, the sediments by other signs. The tinting shows increase in intensity of metamorphism on approaching the boundary of the igneous rock.

upon the rocks, and therefore in affecting the soils to which they give rise.

Among the gneisses and schists which the student may usefully study in specimens are the following :—

GRANITOID GNEISS.—A coarsely crystalline mixture of felspar, quartz, and mica or amphibole. The foliation is usually not so freely developed as in schists. The foliation-planes often bend round large porphyritic crystals.

MICA-SCHIST.—A finely foliated rock consisting of folia of quartz and mica. Felspar is often present.

HORNBLENDE-SCHIST.—This differs from the last rock in the occurrence of hornblende (amphibole) in the place of mica. The hornblende is often found in needle-like crystals.

MARBLE.—A crystalline limestone; is often associated with schists. It may or may not be schistose itself; if it is, it often contains mica. It is produced by the metamorphism of ordinary limestones. The well-known Carrara marble has been produced by metamorphism of a fossiliferous limestone.

II. CONCRETIONS

Mineral particles have a tendency in some circumstances to collect around a nucleus to form *concretions.* The process is spoken of as concretionary action, but it is ill understood. In some cases the presence of organic matter is clearly concerned in the process; in others, again, as clearly not so concerned. Should the nucleus be minute and the process occur under conditions of symmetry, a spherical concretion will result. In other cases the concretions are elliptical, cylindrical, or irregular. Aggregates of concretions may occur, as in the well-known magnesian limestone concretions of the Durham coast. In some cases the formation of the concretion is accompanied by contraction, causing radial and concentric cracks, which may afterwards be filled with spar, giving rise to the *septarian nodules*, which are frequent in many clays. A section of such a nodule is shown in Fig. 26.

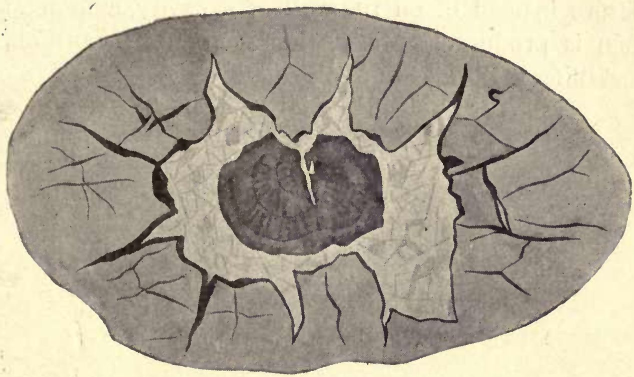


FIG. 26.

SECTION OF SEPTARIAN NODULE.

Many concretions are composed of substances of economic value. Septaria, for instance, may be used in the manufacture of Portland cement. The nodular concretions of flint are useful for road-metal, for building-stone, and in the manufacture of china. Phosphatic nodules in the form of concretions have been worked in many places for manure.

III. SEGREGATIONS

Should a cavity occur in a rock in which mineral matter is deposited on the walls of the cavity and then in successive growths from without inward, a *segregation* is formed. The cavity may be completely filled, as in the case of the amygdules of amygdaloidal lavas, or only partially so, when a *geode* or *potato-stone* results. Should deposition occur on the sides of a fissure instead of on the wall of a cavity, a mineral vein is produced. Many, though by no means all, metalliferous veins are of this nature.

SECTION II

THE OPERATIONS OF GEOLOGICAL AGENTS

CHAPTER VIII

WEATHERING

THE rocks which compose the surface of the solid ground are liable to continual change. The solid rocks are broken up, the materials carried elsewhere, and eventually redeposited on other portions of the land, on the floor of fresh-water areas, or on the sea-floor. The processes of breaking up the rocks and their transport elsewhere are spoken of as *denudation*, and this denudation is described as being *sub-aërial* or *marine*, being, in the former case, effected by agents working over the general surface of the land; in the latter case, by the sea.

Sub-aërial denudation will be first considered. It may be divided into three processes, viz. :—

1. *Weathering*. 2. *Transport*. 3. *Corrasion*.

The processes of weathering cause the breaking up of pre-existing rock into fragments which are adapted for transport. The act of transport is performed on land by simple gravitation, or by wind, rivers, and land-ice. During transport the material which is transported is rubbed against the rocks over which it passes, breaking fragments from them, which add to the transported material. This fracture and comminution of rocks during transport is corrasion—a term which has recently been used, since the necessity of distinguishing this act of fracture from that performed by the weather was recognised.

WEATHERING.—As the action of weathering is primarily responsible for the production of soils, its study is of peculiar importance to the agriculturist.

The comminution of rocks during the processes of weathering is brought about by various agencies, of which the principal are change of temperature, rain, and organisms.

Change of temperature is most efficacious in splitting rocks when the variations of temperature are very marked. In desert regions, where the day temperatures are often very high and those of the night very low, the rocks undergo alternate expansion and contraction. Not only do different grains of a rock composed of different minerals expand unequally, but the amount of expansion in some minerals is more in the direction of certain crystalline axes than of others. The rocks are accordingly broken at first into fragments of varying sizes, often bounded by divisional planes, as joints; but as the process is continued on these fragments as well as on the solid rock, the larger fragments become broken up into smaller and smaller pieces, until the rock may be eventually reduced to a loose mass, consisting of particles composed of the original rock-grains.

Though the process of disintegration by alternate expansion and contraction is well studied in desert regions, where the process is not in any marked degree masked by other changes proceeding simultaneously, it must produce its effect elsewhere as the result of diurnal and also of seasonal changes of temperature.

In regions where the temperature falls sufficiently to cause water to freeze at times, the effect of temperature in breaking up rocks is due to the conversion of water into ice. All rocks contain a greater or less quantity of water, which permeates the rock, and to this is added the water which soaks through from the surface. When this water freezes, it expands considerably on assuming the solid state, and accordingly wedges rock-fragments from the solid rock. This is very noticeable on cliff-faces in hilly districts. The water percolates into the fissures of the rock, there freezes, and causes the rocks to split along these fissures. The fragments may adhere to the cliff after the formation of the ice, owing to the ice itself binding them, and accordingly the fragments thus rent off frequently fall immediately after a thaw. Having fallen, the water in the interstices between the rock particles may subsequently freeze, and in this way the rock may be eventually, by frost-action only, broken up into a loose mass formed by the constituent particles of the original rock.

Though the process is easily studied in the case of cliffs, it also takes place on level ground, and may be observed in many roadways which become broken up by frost, with the production of incoherent material on the surface.

This action of frost is, of course, similar in the case of soils, when they are compact. A heavy clay soil is thus broken up by frost during a hard winter in Britain.

The result of change of temperature on rocks, whether with or without frost-action, is essentially mechanical, with no chemical change. The material produced is therefore similar in composition to the rock from which it is derived, and is no more adapted for vegetable growth than the rock itself, except in so far as its comminution assists that growth.

The action of rain is of very great importance, mainly on account of the chemical changes which are produced by it. The mechanical action of rain is limited to the comminution of masses which are not very coherent before the action takes place. Thus stiff clay may be to some extent disintegrated by the impact of raindrops upon its surface, but the effects are of little consequence.

The chemical changes are due to the existence of substances in rocks which are directly soluble in water itself, or are dissolved by substances in the atmosphere, which are capable of acting as solvents in the presence of water, whether they are taken up by the water or not.

Pure water is capable of dissolving various salts, as common salt, with ease; though most of the rock-components are said to be insoluble in pure water, it must be remembered that solubility is a matter of degree, and that, given time enough, pure water may extract some matter from rocks, even though that matter is in the ordinary sense of the term insoluble.

It is in conjunction with other substances that the solvent action of water is most marked. The principal substances which in this way produce a solvent action upon the rocks are oxygen, carbon dioxide, and various organic acids; and as a result of the action various oxides, hydrates, and carbonates are produced from some of the rock-constituents. The removal of the soluble materials by water frequently, though not necessarily, produces a rotting of the rock, which is thus rendered more prone than before to mechanical disintegration; and accordingly, when conditions are favourable, we frequently find thick accumulations of incoherent material covering the solid rocks beneath, when the latter are subjected to the solvent action of surface waters.

We may now proceed to consider the effects of this solvent action on the rocks, first taking into account the effects of the various solvents, and then discussing the effects of the solvents upon various kinds of rocks.

The oxygen in the air, in the presence of water, is capable of converting many mineral salts into oxides, though there is usually a further change into hydrates. The rusting of a needle is a familiar instance of oxidation, and many of the changes which occur in minerals are closely akin to rusting, even to the production of a rusty-looking crust upon the surfaces of the rocks. A change, due to oxygen, which is of some importance, is the conversion of sulphides into sulphates. Thus iron pyrites, the sulphide of iron, may be converted into sulphate of iron. A further change frequently occurs, the sulphate being converted into iron hydrate, and this is accompanied by liberation of sulphuric acid, which is thus rendered available as a solvent.

The modification of oxygen known as ozone which occurs in the atmosphere, probably plays a considerable part in the processes of oxidation; for, though it is small in quantity, it is active. It is found especially near the sea, and is produced during thunder-storms.

The peroxide of hydrogen, hydroxyl, also occurring in small quantities in the atmosphere, is probably also very efficacious as an oxidiser.

The carbon dioxide of the atmosphere, which is found in variable quantities in the air (there being present on the average about ·04 per cent. of this gas), combines with rain-water to form carbonic acid. This acid acts as a solvent upon many rock-constituents; it converts the insoluble carbonate of lime into a soluble bicarbonate, and the insoluble silicates of many substances into soluble carbonates. It is, indeed, the most important of the constituents of the atmosphere which, in the presence of water, promote the decay of rocks.

The effect of organic acids is in many respects similar to that of carbonic acid, and the resultant products of the work of these acids are often carbonates, though, owing to the influence of bacteria, nitrates may be formed. These acids are chiefly taken up by rain-water after it has fallen upon the soil, and they then exert their influence upon the underlying rocks.

We may now briefly consider the action of the various solvents upon some representative rocks, and will commence with a notice of the changes which they produce upon igneous rocks.

Granite may be taken as a representative of the acid rocks, so far as weathering is concerned, and it will be instructive to note the manner of its disintegration by weathering action in a moist climate, such as that of England.

Of the three constituents of a normal granite the quartz is but slightly affected by solvents in the rain-water, and remains practically unchanged. Not so the felspar. This mineral, it will be remembered, is a double silicate of alumina, and of a metal or metals of the alkalies or alkaline earths. The aluminium silicate is practically insoluble, but the alkaline silicate is soluble in carbonated water, and is converted into a soluble carbonate, which may be carried away in solution in river water. This change is of very great importance to us in two ways. As orthoclase felspar, a common constituent of granite, contains potassium silicate, the resulting soluble potassium carbonate is rendered available for plant-life. Again, as the result of the chemical change, a mechanical change of profound import is brought about. The hard crystalline felspar is converted into a soft, incoherent mass of silicate of alumina known as kaolin or china clay. If the granite contains a large proportion of felspar, the whole rock may be thus rotted, and indeed we frequently find that this rotting takes place for some distance below the surface of the ground. The weathered granite in parts of Cornwall may be dug out with a spade to a depth many feet below the surface. The rotten rock is thus rendered serviceable for further change into soil, as will be described more fully in the next chapter, and it is also brought into a state in which it is readily transported piecemeal to other places by the various agents of transport, such as running water. The ferro-magnesian constituent, such as mica or amphibole, is also acted upon to some extent; but the change may be considered when we deal with the more basic rocks, which contain, as a general rule, a large proportion of such constituents.

As a typical representative of the basic rocks we may consider the case of basalt. Leaving out of account the ore, which is unimportant to us, and the olivine, the conversion of which into serpentine has already been noticed, we are chiefly concerned with the changes in the felspar and the pyroxene. The plagioclase felspars, which are the dominant felspars of the basic rocks, contain lime silicate. This is converted into carbonate of lime, leaving the aluminium silicate untouched, as in the case of orthoclase. The physical change in the felspar is similar to that which takes place in orthoclase; but as the result of the chemical change carbonate of lime is set free, and rendered available for the formation of limestone rocks. In the felspar which contains soda, carbonate of soda is produced, and may be carried away in solution.

The composition of the ferro-magnesian silicates, as was seen when describing minerals, is varied. Some of the constituents, as the aluminium silicate, are insoluble. Others are soluble, and the effect of solvents on the iron silicates is specially important. The iron may be converted into the insoluble carbonate, but usually the ultimate result is its conversion into hydrate. On account of the fairly large proportion of iron in the ferro-magnesian constituents of many basic rocks, a considerable amount of iron hydrate is produced, which causes the weathered products of these rocks to assume a prevailing rusty yellow, orange, or brown colour.

As the other igneous rocks approach the granitic or basaltic type with regard to their constituents, the changes which occur in the two rocks noticed above will be sufficient to illustrate the nature of the changes produced by weathering in other igneous rocks of common occurrence.

Passing now to the sedimentary rocks, it must be noticed at the outset that as they have been largely derived either directly or indirectly from igneous rocks by processes of denudation operating in past times, the soluble constituents of the minerals have frequently been to a considerable extent leached out of the rocks, and therefore the component particles of sediments are, on the whole, less prone to chemical effects of the weather than those of the igneous group. The disintegration of sediments, therefore, in so far as it is dependent upon chemical action, is often largely due to the removal of the cement which binds the component grains together. The removal of this cement will render the rock incoherent. Of the common cements, silica, carbonate of lime, and hydrates of iron have been noticed as most frequent. Of these the carbonate of lime may be removed in solution as bicarbonate; the hydrates of iron may also be converted by organic acids into soluble substances. The silica is also acted upon by organic acids, which are capable of dissolving it, and thus causing the disintegration of the rock.

Owing to the removal of these cements, arenaceous rocks are often readily disintegrated as the result of weathering action.

Argillaceous rocks, as has been seen, consist of silicate of alumina, mixed with small chips of various minerals. The alumina silicate is unaffected, but the fine state of division of the particles renders the chips of soluble minerals easily affected, and a considerable amount of the material of clays may be carried off in solution.

Pure calcareous rocks are completely soluble in carbonated waters. The insoluble carbonate, as already stated, is converted into a soluble bicarbonate, and removed in solution in river-water. The impurities of many limestones are left behind as an incoherent accumulation, the composition of which depends upon that of the original impurities.

In igneous and aqueous rocks alike, the divisional planes which traverse the rocks are of great importance in influencing chemical action as well as mechanical action during the processes of weathering. Joints especially, which are often vertical or inclined at a high angle to the horizon, are favourably situated to act as channels for the passage of water into the rocks, and we accordingly find that weathering frequently works inward from either side of a joint-plane. This has a very considerable effect on the reduction of rocks into material suitable for ingredients of soils.

The operations of organisms in promoting rock-weathering is a matter of considerable importance to us. They are carried on both mechanically and chemically, and are effected by the agency of animals as well as by that of plants.

The mechanical action of plants is well seen in the case of roots of trees which penetrate the fissures, and as these roots expand upon growth, fragments of rocks are wedged off, and huge masses of rock are often seen to fall from cliffs owing to this cause. But the action of the roots and rootlets of smaller plants, though not at first so apparent as that of trees, is very pronounced. These roots often extend downward for a considerable distance from the surface, and to some extent break up the solid rock, in the same way as the roots of trees break it; their influence is specially marked upon the partly disintegrated rock which lies between the solid rock and the surface soil.

The chemical action due to plants is very great. In the first place, plants act as sponges, and hold the water against rocks for a longer time than it would rest on bare rock, thus increasing the time during which solution can take place. Secondly, they furnish solvent acids, which considerably aid in the disintegration of rocks by the removal of various constituents. Many of these acids are unstable products due to the decomposition of plants. The principal are humic, ulmic, crenic, and hypocrenic acids. They consist of varying proportions of carbon, hydrogen, oxygen, and, in the case of the two last named, of nitrogen also. They are not only capable of affecting various carbonates and silicates which occur in rocks, but they produce a very considerable action upon silica itself, and thus form powerful auxiliaries to carbonic acid in effecting the disintegration of many rocks.

The effect of bacteria in producing nitric acid has already been noticed. As these minute organisms are capable of penetrating into the smallest rock-crevices, their effect in promoting rock disintegration is undoubtedly very marked, in addition to their power of adding substances to the constituents of soils.

The action of animals upon rocks is essentially mechanical. They produce little effect upon solid rocks, but the final disintegration of rocks is accelerated by burrowing animals, as the rabbit, mole, and badger. Above all, as shown by Darwin, the earth-worm is of importance in comminuting the fragments of rock, not only by burrowing, but by passing the materials through their bodies. It must not be supposed, however, that the presence of the earth-worm is universal. In parts of the north-western territories of Canada, for instance, the earth-worm is absent, and the disintegration of the rock-particles is largely carried on by burrowing mammals.

CHAPTER IX

THE FORMATION OF SOIL

SOIL can only accumulate where the amount of loose material produced by weathering is in excess of that removed by transport. Furthermore, other conditions, such as favourable climate, must occur in order that a cultivable soil may be formed; in many desert regions, for example, loose material overlies the solid rock over large areas, but owing to unfavourable climate no cultivable soil is formed.

Cultivable soils are divided into those which are formed *in situ* and those which are due to transport of material from other sources. It is not always easy to separate the two rigidly; for example, boulder-clay is sometimes spoken of as transported soil, but the actual soil is produced *in situ* on the surface of the boulder-clay. The transported soils will be spoken of more fully in a succeeding chapter, and we shall here devote our attention especially to the cultivable soils which are formed *in situ*. It must, however, be understood that much which is here said about soils *in situ* applies also to the transported soils.

Soils consist of a mixture of organic and inorganic matter, the former being derived from plants and animals, and the latter from the rocks. The composition of soils, therefore, varies according to the character of the rocks from which they are derived.

Before considering the variation in the composition of the inorganic materials of soils, it will be well to

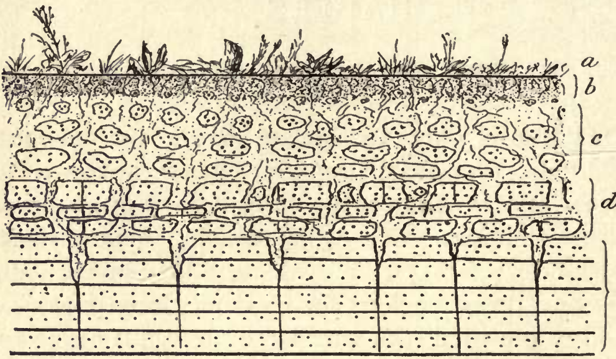


FIG. 27.

DIAGRAMMATIC SECTION SHOWING FORMATION OF SOIL.

a. Vegetable growth.
b. Soil, passing down into :—
c. Subsoil with fragments of sandstone, passing down into :—
d. Brashy rock with finely divided material and rootlets between the fragments. This passes down into :—
e. Sandstone rock, with joints gaping at the top.
Lighter stippling = subsoil and loose material of brash.
Darker stippling = soil.

describe the mode of conversion of rocks into soil, which we are in a position to do after our study of the processes of weathering described in the preceding chapter. If we examine a section such as that exposed in a quarry face, where soil formed *in situ* is found at the summit of the quarry and solid rock at the base, we shall find some such succession as that illustrated in Fig. 27. At the top is the actual soil; below this is the subsoil, in various stages of disintegration; still lower down we find the solid rock, broken up by the action of weathering along the divisional planes; and at the base, the unaltered solid rock. A regular gradation is usually noticeable between two contiguous layers, the rock passing gradually upwards into the *brashy* or broken rock, this also slowly changing into subsoil and the latter into soil. The brash may be penetrated by roots of trees, and will contain a small amount of organic matter. The further reduction of rock-fragments at a higher level causes the brash to pass into subsoil, which consists of fragments of the rock embedded in smaller particles, due to the disintegration of the outer faces of these fragments. As we examine higher parts of this subsoil, the fragments will be found to become smaller, and the proportion of small particles to increase; the amount of organic matter will also tend to increase. When the fragments are few in number, and the organic matter is considerable in quantity, the true soil is reached.

Many variations from such a gradation may be traced, dependent upon the character of the underlying rock and on the nature of the agents of weathering. With a clayey rock the larger fragments in the subsoil may be few, or altogether absent, and the same result may be obtained in other rocks than clay if the weathering is mainly brought about by chemical action; thus the subsoil above a basalt may be a loose, iron-stained, sandy material. Should the underlying rock be a sandstone, the large fragments may be numerous in the lower part of the subsoil, and the same may be the case even with an underlying well-jointed clay rock, if frost be the prime factor in disintegration of the rock.

In soil which has been cultivated the operations of cultivation may have produced a marked physical difference between the conditions of the soil and those of the subsoil, and accordingly, while natural soils often show the gradual passage into the subsoil, which has been noted above, there may be, and often is, a sharp plane of demarcation between a cultivated soil and the subsoil which underlies it.

Consideration of the constituents of various soils will be facilitated if we divide those constituents into three groups, namely, the particles derived from rocks, such as sand, clay, and lime; the materials which are present in the ash of plants when burned, which must originally have been derived from the soils, as alkaline compounds and silica; and, thirdly, the materials derived in large part from the atmosphere.

As a great part of the inorganic matter of soils is derived from the stratified rocks, we may conveniently consider this matter at the outset. The principal constituents of these rocks are sand, clay, and lime in varying proportions, and accordingly we may have sandy soils, clayey soils, and calcareous soils. The latter always contain a certain amount of non-calcareous material which is the residue of that part of the limestone which has been carried away in solution, whereas sandy soils and clayey soils may contain their respective inorganic constituents in a state of comparative purity.

Many rocks are, as has been seen, composed of combinations of different kinds of substances. Thus we may have mixtures of sand and clay; or, the soil may be derived from the weathering of rocks of more than one kind, in which case similar combinations may occur. A mixture of sand and clay forms a *loamy* soil, the soil being spoken of as a sandy or a clayey loam, according to the preponderance of sand or clay. A mixture of clay and limestone is, as already stated, termed *calcareous marl*. Thirdly, we may have a mixture of sand and lime in various proportions, giving rise to what has been termed *calcarene* soil.

Of the other constituents of sedimentary rocks, the oxides and hydrates of iron are frequently introduced into soils, being largely derived from the ferruginous constituents of sedimentary rocks.

Again, many sands and clays still retain some of the alkaline compounds which were components of the igneous rocks from which the particles have been at one time worn away, and these may furnish material such as carbonate of potash to the soil. The exact condition under which alkalies exist in various rocks is still a moot point, into the discussion of which we cannot enter here.

The igneous rocks contain a number of soluble materials necessary for the growth of plants. It by no means follows, however, that these rocks are necessarily covered by fertile soils. Many granites, for example, contain abundance of such necessary materials, but if these materials are in a condition of practical insolubility, they are useless for the purpose of enriching the soil.

The pyroclastic rocks frequently contain valuable soil-constituents in a state in which they are readily extracted by weathering action, and accordingly we find the soil of volcanic regions is often remarkably fertile.

We may now pass on to the consideration of those materials of the soil which are taken up by plants, some of which have indeed been alluded to in the above paragraphs. In addition to silica the materials which are important to plants are potash, lime, magnesia, phosphoric acid, and sulphuric acid. Of these, the potash, lime, and magnesia have already been accounted for as present in various rocks. The phosphoric acid was no doubt originally of inorganic origin. It is found combined with lime in crystalline rocks in the mineral apatite. It has been through long ages abstracted from the earth to form the bones of animals and parts of the tests of some invertebrates, and much of the phosphoric acid of rocks is no doubt directly introduced by the agency of organisms.

The materials taken up by plants are again restored to the soil upon the death of the plant, though as a result of bad cultivation much of them is frequently removed from the soil.

The other constituents of soil are mainly derived from the atmosphere. The most important of these are water, carbon compounds, and nitrogen.

It has already been stated that all rocks contain water. Some of this is locked up in the minerals, but a large part is interstitial water contained between the particles of the rock; this is spoken of as *quarry water.* In addition to this there is the important supply obtained from the atmosphere at the present day, upon the amount of which the fertility of soil largely depends.

The vegetable matter which enters into the composition of soil passes by change into a substance known as *humus*. This is a dark brown mouldy substance, having no definite composition. Its average composition is: carbon, 54·8 %; hydrogen, 4·8 %; oxygen and nitrogen, 40·4 %. It is of great importance to the agriculturist on account of its power of holding ammonia in a form in which it can be readily assimilated.

The character of the soil differs markedly according to the proportion of humus which it contains, and this proportion varies greatly; and accordingly we can have every gradation from the sterile soil of desert regions to the rich peat-accumulations of temperate regions, in which the proportion of humus (which has undergone a certain amount of alteration) is very high. The conditions under which peat is formed will be described more fully in the sequel.

Nitrogen occurs in the soil in the free form, or as ammonia, nitric acid, and nitrates. The importance of bacteria in promoting nitrification has already been noticed. As a result of this nitrification, ammonia, nitric acid, carbon dioxide, and water are formed. Of these, ammonia salts and nitric acid are of importance as plant-food, while the nitric acid in combination with bases acts as a fertiliser.

The physical conditions under which soils exist is also a matter of considerable importance, as producing a very marked effect upon the fertility of soils.

Although soils need not differ much in composition from the rocks from which they are derived, they tend to form more porous masses; indeed, the amount of interspaces in soils has been calculated to form on the average about fifty per cent. in volume. This produces a great effect on the capacity of the soil for receiving and retaining moisture. This capacity, of course, varies greatly according to the nature of the soil. The following figures, obtained by Meister, illustrate this and will be found useful:—

Soil.	Percentage of water imbibed.
Clay	50
Loam	60·1
Humus	70·3
Peat	63·7
Lime	59·9
Chalk	49·5
Sandy	45·4–65·2

The size and shape of the particles of soil are important as affecting in a marked degree the porosity of the soil and also its capillarity.

The action of capillarity is to some extent of an opposite character to that of porosity. Owing to porosity, the water which falls on the soil tends to soak inward, while owing to capillarity, some of the water which has entered the soil during rainfall and has soaked downward is again brought toward the surface, thus keeping the soil moist.

A soil which has the physical properties favourable to reception and retention of water and to the action of roots, may have any necessary ingredients for plant-culture which it does not contain added to it, but this addition will be useless should the physical conditions be unfavourable to plant-growth.

One effect of the downward percolation of water upon some soils may be conveniently noticed here. In certain soils, such as clays containing carbonate of lime, the water, percolating downward, carries the lime in solution, and also particles of clay in mechanical suspension, to the subsoil, at the top of which the clay is deposited and the lime consolidated, giving rise to an impervious layer beneath the soil, which is termed "hard-pan." Similar "hard-pans," formed of iron compounds, are often found at the base of peat-accumulations. It may be necessary to break these up in order to render the soil fertile.

CHAPTER X

AGENTS OF TRANSPORT AND DEPOSITION

WE have seen in the preceding chapters that the soil which is formed *in situ* is produced by weathering of the rock beneath. In places where there is no soil the weathered material is removed, as fast as it is loosened by disintegration of the solid rocks. Even when soil covers the rock, however, some transport takes place, and accordingly the soil is constantly changing, being swept away from the surface by wind and rain-runnels, while it is renovated by the addition of fresh matter from beneath. The soil may, in fact, be compared to the skin of an animal which is replaced from below as it is worn away at the surface.

The material which is transported is eventually accumulated elsewhere. By the operation of the transporting agents, usually working downhill, owing to gravitation, this material is gradually borne seaward, and if sufficient time were granted, it would eventually find its way to the sea and be deposited upon the sea-floor, to form marine deposits. The process, however, is slow and to some extent interrupted by pauses, and much of the transported material is accumulated upon the surface of the land when the conditions are favourable to its settlement, and it may give rise to transported cultivable soils.

The principal agents of transport on the land-surfaces are wind, rain-water runnels, streams and rivers, and glaciers, and we may consider the action of these various agents in the order in which we have named them.

The effect of wind as an agent of transport is well seen in the case of dust-storms, in which the dust is raised into the air by whirling currents and carried along, often for long distances, to accumulate in sheltered spots. The most marked effect of wind as a transporting agent is noticeable in the arid tracts of desert regions, where wind is the main factor in the removal of material from one place to another. Where the ground is occupied by vegetation, the tangled roots knit the soil together and diminish the efficiency of the wind in removing the particles, but though the action is thus retarded, it cannot be regarded as a negligible factor.

During the transport of particles by wind a certain amount of corrasion, or gnawing away of solid rock, takes place, but it is not important in connection with our present study.

The material transported by the wind may have some effect on the composition of soils. Thus the finer volcanic dust, rich in many soluble substances, is carried by the wind far from its source, and it may increase the fertility of soils on to which it falls. Volcanic dust in Iceland has frequently been carried in some quantity to Scandinavia and to the North of Scotland.

To the student of agriculture the wind is also of importance from its tendency in certain circumstances to render cultivated land useless. This is especially the case where sand-hills, or sand-dunes as they are termed, exist, as along many flat sea-coasts in Britain and elsewhere.

With a prevalent on-shore wind, the sand which is laid bare at low tide is blown inland, and accumulates in large wave-like hills composed of loose sand. These hills may rise to scores of feet, or in rare cases to some hundreds of feet, in height. Under the influence of the wind they advance inland, and frequently cover the soil of fertile tracts, rendering these tracts useless. The dunes may be rendered innocuous by planting them with trees and grasses which are capable of living upon them; the roots bind the sand together and render it stationary. In many places pines are planted to check the advance of dunes, while in some localities, as on the Norfolk coast, the marram-grass (*Psamma arenaria*) serves a similar purpose.

In the interior of continents with scanty rainfall, where there is an abundant supply of dust, derived from the action of the wind upon such accumulations as glacial mud, this dust settles in hollows and tracts where the air is tranquil and forms an accumulation, often of considerable thickness, to which the term *loess* is applied. The accumulation consists of minute grains of minerals, and is penetrated by upright tubes in which the roots of plants have once existed; these tubes are generally lined with carbonate of lime. Various saline and alkaline substances may occur in the loess, which is analogous to the accumulations now being piled up in steppes. Certain modifications of this steppe-accumulation, under less arid conditions, allowing of the intermixture of a considerable amount of humus, cause the formation of the fertile Tchermosem or Black Earth of Southern Russia. The loess is fairly well developed in Central Europe from Belgium to the south-east, and it is widely distributed in Central Asia from the west to the shores of the Yellow Sea.

The action of rain-water runnels is distinguishable from that of streams, the differences being due mainly to small volume and inconstant action of rain-water runnels. So far as soil is concerned, their transporting effects are constructive in some places and destructive in others.

Their constructive action is specially noticeable on inclines or at the foot of inclines. During and after rainfall, the finer particles are carried downhill by the runnels and deposited upon gentler parts of the slope or on flat ground at the foot of the slope. The detritus of hillsides thus slowly creeps down toward the foot of the hill; and the lower slopes near the valley floor, as well as parts of the actual floor, thus receive a mass of material known as *rainwash*. As it will in all probability be composed of a varied assortment of materials, and as it often accumulates in positions in which it receives a steady supply of water, rainwash frequently supplies an excellent soil for agricultural purposes. It is, indeed, a typical example of a transported soil.

There is every gradation, from ordinary rainwash to the widespread fluviatile accumulations which are found especially on the floors of plains bordering upland regions; these will be noticed under the head of River-action.

The destructive effect of rain is due to the removal of cultivable soil from the surface by its action. Rivers when swollen during floods are often turbid and of an earthy colour owing to the removal of soil from the surfaces of fields by rain-water runnels, and its carriage into the river. Land which is cultivated on somewhat steep slopes is specially liable to removal of its soil owing to this cause. To counteract this, sloping land has been frequently cultivated in terraces. The larger loose stones have been collected from the soil and piled up into banks, and the ground between these has been levelled. The level surface is cultivated, and the smallness of slope prevents the soil from being washed away, while the large fragments built into the banks are too heavy for removal. Much sloping land was formerly cultivated in our upland regions in this manner, and the old cultivation terraces or *lynchets* often form a marked feature in the scenery of many of our upland districts, as in many parts of the West Riding of Yorkshire.

Rivers are the most important agents of transport in those regions where cultivation of the ground is extensively carried on. Their action is both destructive and constructive, but though the destructive action is locally injurious to the agriculturist, it is in the long run of benefit to the soil. Were the disintegrated material not removed, it would accumulate to such an extent as to check further rock-waste, and the nutritive matter of the existing waste would be gradually extracted by plants, leaving the soil sterile.

Rivers owe their existence to rain. Much of this rain is absorbed by the porous rocks of the earth's crust, but the water which is thus absorbed is to a large extent returned to the surface, especially in the form of *springs.* Each important tributary of a river usually originates at a spring. The nature of springs, and the conditions under which underground water accumulates and is discharged, are, however, matters of so great import to us that they must be considered, at a later period, in a separate chapter.

As a river flows seaward, carrying with it the débris which is supplied to it by rain-runnels and other agents, it may or may not corrade its channel, causing the channel to be lowered. In some places rivers are engaged in thus lowering their channels, but in other places they actually raise these channels. It is desirable that we should learn something concerning the conditions under which rivers lower or raise their beds.

Running water possesses a certain amount of *energy*, or capacity for doing work. The amount of energy of a river depends mainly upon the velocity of the stream and upon the volume of water, increasing with increase of these.

Now imagine a stream of uniform volume running down a uniformly inclined slope, and that this stream is supplied with as much material as it can possibly carry. Its energy will be completely utilised in this act of transport, and none will be available for corrasion of its bed ; therefore, so long as the conditions remain the same, it will neither corrade nor deposit, but will continue to carry its load downward. If the supply of material be diminished, some of the stream's energy will be available for corrasion, which will be performed by the friction and impact of the remaining sediment against the river-bottom, and the bed will be lowered. If, on the other hand, material be added instead of being removed, the stream will not have sufficient energy to carry this onward, and it will be deposited, thus raising the bed.

If, instead of having a uniform slope, we have one which falls the same amount as the uniform slope in a given distance, but not uniformly, being in places steeper and in other places gentler than the uniform slope, and if the stream over this slope be supplied with enough material to utilise all its energy had the slope been uniform, the energy, being increased over the steeper parts owing to increased velocity of the stream, will be partly available for corrasion, which will there occur, while with diminished energy over the gentler portions the stream will deposit over those parts of its course. These processes would go on in the circumstances until, by corrasion in the steep parts and deposit in the gentle slopes, a uniform slope having the inclination of our ideal slope was produced. Such a line, when the stream can neither erode nor deposit, is termed the *base-line of erosion* of streams, and if the conditions of river-erosion remain the same, all rivers tend to establish these base-lines.

As rivers increase in volume as they approach the sea, owing to reception of tributary waters, erosion, so far as it depends upon volume, would be greatest at the mouth, where the volume is greatest, least at the source, where there is no water. In nature, however, the velocity is checked at the mouth, and the stream cannot corrade below sea-level. Consequently the greatest amount of corrasion occurs somewhere between mouth and source, where the combined effects of volume and velocity are greatest. The base-line of a river is, consequently, a curved

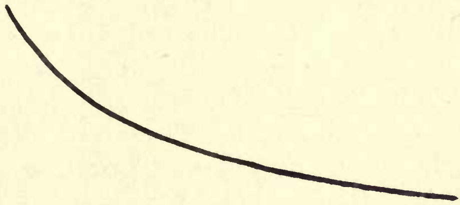


FIG. 28.
BASE-LINE OF EROSION.

line ever increasing in steepness from mouth to source, as shown in Fig. 28.

In many land-areas of great antiquity the rivers have established their base-lines of erosion, and no downward corrasion is taking place. This is the case with a large number of the rivers of our island.

As the axis of uplift of a country tends to determine the slope of the rocks as well as the position of the main watershed, the principal streams often run in the direction of the slope of the rocks, and may be termed *dip-streams* (for definition of *dip* see p. 144). They may accordingly traverse rocks of very different characters. For instance, the Thames starts on the Oolites consisting of alternating deposits of hard limestones and sandstones and soft clays; then passes over the Lower Greensand, the Gault Clay, the Chalk, and finally the London Clay.

The tributaries, on the other hand, tend to run at right angles to the direction of slope of the rocks along what is termed the direction of *strike* (for definition of this term see p. 145). They may, therefore, be termed *strike-streams*. These have a tendency to establish their courses along the softer rocks, which are more readily worn away into valleys, while the intervening rocks have a gentle slope in the direction in which the rocks are sloping, if that slope is not in itself great, and a steeper slope in the opposite direction. These two slopes are respectively termed *dip-slopes* and *escarpments*. As the stream usually works along the junction between soft rock and underlying hard rock more readily than into the latter, the strike-streams frequently wear their valleys sideways, causing recession of the escarpments, a fact of some importance to the agriculturist when combined with other conditions which will presently be noticed. Two great escarpments traverse the East of England in a general north-east and south-west direction, and overlook two plains. The most westerly is the escarpment of the Oolites, running from Yorkshire to Dorsetshire, and overlooking the great plain of the Trias and Lias, while the easterly one is the escarpment of the Chalk, which runs parallel to the former and overlooks the plain of the Jurassic Clays and Gault. Minor escarpments also occur which locally attain considerable importance. On the south-east side of the chalk escarpment is a third plain, that of the London Clay. On these plains much of the best cultivable soil of England is found.

When downward corrasion has ceased, *lateral corrasion* becomes effective, and causes rivers to widen their valleys, giving rise to plains which are often eminently cultivable.

The bulk of transported material is carried in the lower layers of the stream, while the upper parts have much less material in suspension, and accordingly may have energy available for corrasion which will cause the cutting away of the banks if the conditions are favourable. If the river were absolutely straight, such corrasion would not occur, but when the streams are curved, the water, owing to inertia, tends to flow onward in the direction in which it was proceeding in the part of its course just above the curve. It accordingly cuts into the concave bend of the stream, and owing to the existence of an eddy, will deposit material at the convex side, thus producing a lateral wandering of the stream and increasing the curve into a *meander*. We accordingly find that many streams in lowland tracts are marked by a series of meanders, as shown in Fig. 29. As the meanders increase sideways, and move down-stream, the width of river valleys is perceptibly increased, and the steeper valley slopes may eventually terminate against the river plain in some such position as the lines *a b* and *c d* in the figure.

In regions of considerable rainfall the width of the valleys is increased by weathering and by the effect of rain-runnels on the sides of the valleys, and accordingly gorges are infrequent in rainy regions as compared with arid ones.

When a dip-stream flows over rocks of different degrees of hardness, and the river is a *young* one, which has not had time to establish its base-line of erosion over its entire course, it will produce

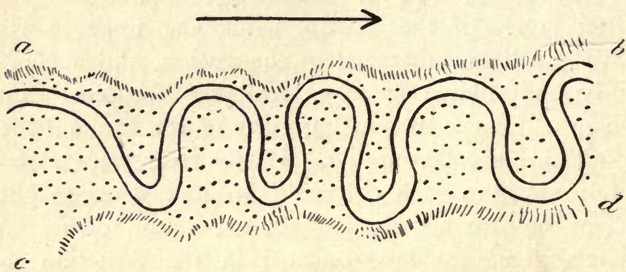


FIG. 29.

MEANDERS OF STREAM.

a b, *c d*=Margins of meander-belt.
Dotted part is alluvium.
The arrow shows direction of flow of stream.

temporary base-lines when passing over the softer rocks, which are readily worn away, and may flow over the harder rocks in rapids or waterfalls for some considerable time before the base-line is established along those portions of its course. During the temporary establishment of the base-lines over the softer rocks, the side tributaries flowing in over those rocks may cut far backwards from their junction with the main stream, and may even establish base-lines of their own along considerable portions of their courses. The section of the main stream will show a line of flow of a character resembling that exhibited in Fig. 30, and the stream will cut gorges in the hard rocks between *x* and *y*, where lateral corrasion is inefficient and the rocks do not yield readily to weathering at the valley sides, and will widen its valley between *y* and *x*, where lateral corrasion is effective, owing to establishment of temporary base-lines.

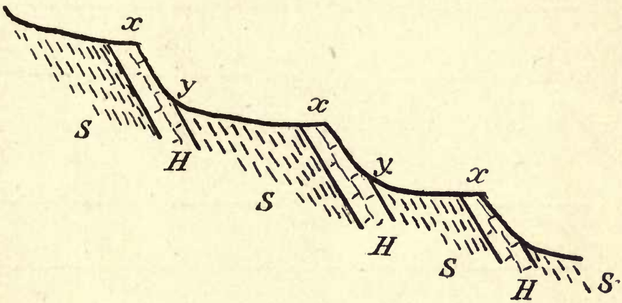


FIG. 30.

ESTABLISHMENT OF TEMPORARY BASE-LINES.

S = Soft rocks. *H* = Hard rocks.

At this stage of the existence of a river and its tributaries the map of the district will appear somewhat as represented in Fig. 31. The plains over the soft rock, due partly to lateral corrasion causing meandering of the streams, partly also to weathering, will be in a condition in which they are suitable for the occurrence of further changes which may render them cultivable.

From what has been said above, it will be seen that rocks form their own valleys by corrasion during the transport of sediment, the valleys being deepened by downward corrasion and widened by lateral corrasion, assisted by weathering.

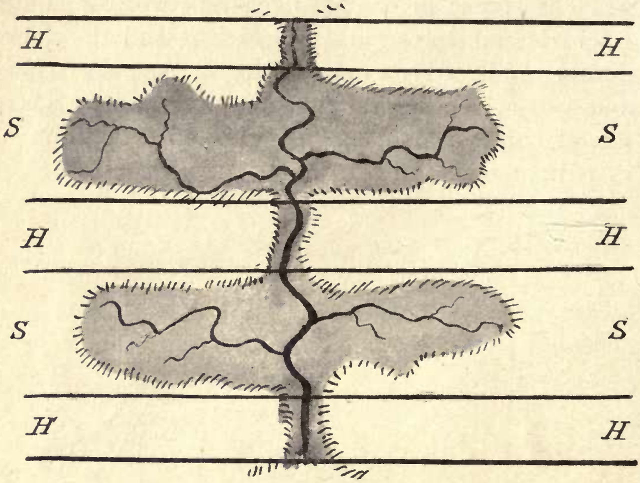


FIG. 31.

PLAN OF RIVER AND TRIBUTARIES.

Showing gorges in hard rocks, *HH*, and wide valleys in soft rocks, *SS*. The valleys are shown in grey tint.

We must now consider the rivers as agents of deposit, for they give rise to very important cultivable soils.

It is during periods of flood that deposit, as well as corrasion, mainly occurs, the intervening periods of quiet flow being marked by a greatly diminished amount of material in the river, owing to the diminution of supply and also of transporting power. It has been calculated that the transporting power of a river varies as the sixth power of its velocity, and consequently it is enormously increased during floods.

The increased volume of the water also causes the river to overflow its banks, and as the velocity of the flood-water on the banks is less than that in the bed of the stream, material is frequently deposited on the sides of the bed, gradually building them up. The greatest amount is deposited near the stream, and less and less as the stream is quitted, and accordingly the deposited material will have a convex upper slope. This is usually inappreciable when the stream traverses fairly flat ground, and we there meet with plains due to deposit on the pre-existing valley floor. These are *alluvial plains*, for the material which is deposited by rivers is termed *alluvium*. Should the alluvium be deposited against a considerable slope, on the other hand, the surface of the deposit may possess a marked inclination, and *alluvial cones* are formed. Alluvial deposits vary considerably in composition according to the nature of the rocks from which they are derived; they also show marked variations in coarseness, even in very short distances.

In hilly regions the torrents which course down valley sides are often charged with coarse material, which, owing to the steepness of the slope, they can carry onward until they reach the more level ground at the valley bottom. The main stream, though of greater volume than the tributary, may be unable to carry the coarse material on account of the slight velocity due to diminished slope, and this material is built up as an alluvial cone or dry delta, which drives the main stream to the side of the main valley opposite to that from which the tributary comes. These alluvial cones, like ordinary river deltas, frequently cause the tributary to divide into many branches, of which one is usually occupied by the stream-water at any one time. They are frequently very fertile, and can be readily irrigated, as the stream may flow along the highest part of the curved slope of the cone.

If a mountain chain overlooks a fairly flat tract of country, the alluvial cones may coalesce over the plain at the foot of the chain and give rise to fertile tracts of alluvial soil over very extensive areas. Such tracts are found in many parts of the world; indeed, they occur wherever the climatic conditions favour the cultivation of the soil formed under the physical conditions mentioned above.

It is in the lower parts of river valleys, where the base-line of erosion has been attained, that alluvial plains are extensively developed. Accordingly we find them in the case of comparatively young rivers above gorges, where softer rocks underlie the river-bed, and also along the courses of the strike-streams formed in the manner described on page 110. They are also extensively developed along the river-banks towards the mouths of many rivers. The materials of these plains are often very varied. Owing to differences in the velocity of the stream at different times, particles of different degrees of coarseness become mixed, giving rise to loams. In places the commingling of land shells and fresh-water shells adds a certain amount of lime to the deposit, and accumulations of drift-wood may give rise to humus. The finer material deposited on the flood plains is thus cultivable under proper climatic conditions in a marked degree. The river-bed may be receiving deposits of much greater coarseness than those of the flood plain beyond the bed, causing gravel to be laid down in close association with finer loam, and as the river-bed wanders these gravel patches are often distributed somewhat capriciously among the loams of an alluvial plain. Many of the gravel pits of inland regions are dug amongst the alluvia of streams, or those relics of

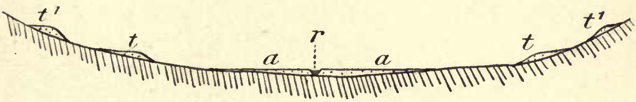


FIG. 32.

SECTION ACROSS VALLEY SHOWING RIVER-TERRACES.

The oblique lines represent the underlying rocks.
$t\,t^1$ = River-terraces. $a\,a$ = Alluvium. r = River.

ancient alluvia which, owing to the deepening of a river-bed, remain on the sides of the river as *river-terraces*, as shown in Fig. 32. These river-terraces have often determined the sites of many settlements, owing to their being near water, their freedom from floods, their ability to furnish a soil, and, above all, their capacity for storing and furnishing a water-supply. We shall have occasion to refer to this last capacity in a subsequent chapter.

In certain circumstances parts of a river valley may be converted into a lake. Lakes may be formed by excavation of part of the valley floor to a lower level than that of part of the river-bed nearer to the mouth of the stream. Glaciers are by many believed to be the most effective agents in such excavation, and it is supposed that they can scoop hollows to form lake-basins, which afterwards become filled with water. Lakes, again, may be formed by the accumulation of natural dams, such as are produced by landslips and glacial moraines. The largest lakes are due to earth-movements, which may raise a part of a river-course above the level of a portion up-stream, when a lake-basin is produced. In arid regions these lakes may be temporary and never filled to the brim;

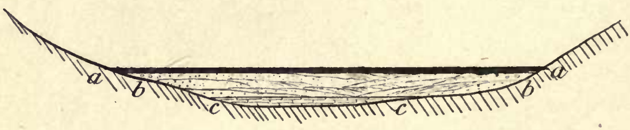


FIG. 33.

SECTION ACROSS FILLED-IN LAKE-BASIN.

a a=Peat. *b b*=Gravel, sand, and mud. *c c*=Shell-marl.

such lakes have no outlet to the sea. In humid regions the river will fill the hollow to the brim, and outflow will occur.[1]

Lakes are temporary, for the rivers at once commence to fill up the lake, forming deltaic accumulations at their mouths, while in deeper parts of the lake, organisms as fresh-water shell-fish often flourish so abundantly that they form deposits of marl on the floor of the lake. The lake is eventually silted up and a *turbary* or peat-moss formed upon

[1] The lakes of arid regions, owing to the evaporation of water, often possess deposits of various salts, which have been precipitated on the lake floor. Some of these are useful as fertilisers, and will be noticed in a later chapter.

its surface, through which the stream meanders. Fig. 33 shows a section through the accumulations which may be formed in a filled-up lake.

Owing to the growth of peat, the sites of ancient lakes frequently exhibit a very fertile soil. Many of the cultivated tracts of mountain regions are found on the sites of vanished lakes. The shell-marl may often be dug from no great depth in the case of lakes which were originally shallow, thus furnishing a fertiliser for the peaty soil above.

CHAPTER XI

AGENTS OF TRANSPORT AND DEPOSITION
continued

GLACIERS AND ICE-SHEETS

IN regions where parts of the land lie above the snow-line the vapour precipitated from the atmosphere falls as snow, which gradually accumulates and becomes consolidated, first into a granular substance known as *névé* and finally into ice. This ice moves slowly down slopes, and the moving ice is known as a *glacier*. Where the snow-fields are of no great extent the glaciers which arise from them occupy valleys, as in parts of Switzerland and Norway; but where the supply of snow is great, it may be sufficient to give rise to masses of ice which cover hill and valley alike, as in the interior of Greenland. Such a mass is known as an *ice-sheet*.

The laws which control the flow of rivers are, to a large extent, operative in the case of moving land ice. Thus the steeper the slope, the greater will be the velocity of the ice, other things being equal, and the glacier, like the river, is retarded at the sides and base by friction against its bed. Again, at a curve, the current is most rapid at the concave side of the glacier-bed. Though the movement of the ice is exceedingly slow as compared with that of running water, the differential movement of the ice is sufficiently marked to produce important results. As the ice cannot accommodate itself to the irregularities of its bed or to the different rates of flow in different parts of its mass as a river does, it becomes cracked, and the cracks, or *crevasses* as they are termed, exert some influence on the glacier as a transporting agent.

One marked difference between the action of glaciers and that of rivers is that in the case of the former much of the material which is swept on to the glacier is transported upon its surface. The material which falls from the hillsides, owing to the action of frost and runnels, is piled upon the sides of a glacier in the form of *lateral* moraines (*l*, *l*, Fig. 34). The stones of these moraines, undergoing little change during transport, usually retain the angular outlines which they possessed when detached from the parent rock. When two tributary glaciers unite, the adjacent lateral moraines form a *medial* moraine (*m*) upon the centre of the main glacier. As the ice moves downward it eventually reaches a place where the melting of the ice is sufficient to counterbalance the supply brought from above, if the temperature be sufficiently high to cause this to occur before the ice reaches the sea. Accordingly, except in high latitudes, the glacier ends upon the land, and deposits the material which it has carried on its surface, and some of that which is carried beneath in a way to be presently described as a *terminal* moraine (*t*), which is usually crescentic, with the convex side of the crescent pointing down valley. As glaciers recede owing to amelioration

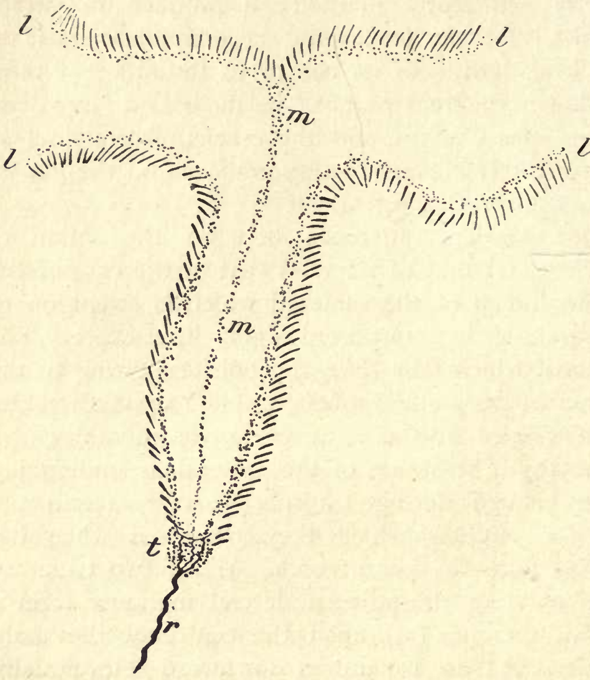


Fig. 34.

PLAN OF GLACIER.

The lines represent slopes of hillsides.

l l = Lateral }
m m = Medial } moraines.
t = Terminal }

r = River issuing from end of glacier.

of the climate, crescent after crescent may be left during periods of pause in the recession, separated by flat tracts sparsely covered with glacial accumulations, and marking periods of active recession. Owing to the cracks or crevasses which traverse the glacier, which frequently engulf streams flowing over the surface, due to the melting of the ice, some of the superficially transported material is carried down beneath the ice, and may reach its base. The sole of the glacier is thus armed with material which, when added to by corrasion of the bed, converts the glacier into an effective rasp, and enables it to wear away its bed.

The effects of glacier-denudation are in some respects different from those of rivers, and must be briefly noticed. The stones held in the sole of the glacier are pressed firmly against the solid rocks of its bed, and are accordingly worn smaller, especially by the slight rounding of the angles. An originally angular stone thus becomes *subangular*—less angular than the original frost-riven block, but not so rounded as the water-worn pebble. It also, if of right texture, receives a polish, and lastly, may have striae or scratches impressed upon it by the hard grains of the rocks beneath being pressed against it during its motion on the ice. A typical subangular scratched glacial *boulder* is accordingly easily recognised, and the recognition is of importance, as the identification of glacial deposits by the student is desirable. An illustration of a typical glacial boulder is given in Fig. 35.

Fresh boulders are constantly being formed by removal of material from the bed of the glacier, and the great bulk of boulders of a glacial deposit formed beneath the ice are doubtless derived from this source. Indeed, in the case of ice-sheets there is no superficial transport where no rocky land projects above the ice, and in that case the whole of the boulders must be derived from the bed of the ice. These boulders will be embedded in the material formed by the grinding down of the rocks and large fragments. This material, owing to the great pressure of the ice, is often in a state of extreme comminution, as may be seen by examina-

FIG. 35.

GLACIAL BOULDER.

tion of the mud carried by the streams issuing from the ice.

If climatic conditions should cause the recession and disappearance of the ice, the ground-moraine and any material held in the mass of the ice will be deposited as *boulder-clay*.

When the ice reaches the sea and portions are carried away as icebergs, the material held in the icebergs will be deposited as a marine boulder-clay having much the same composition as that accumulated upon the land.

The solid rocks are also modified in a peculiar manner by the passage of the ice over them. In a country which had been subjected to ordinary weathering action before its glaciation a covering of superficial material might mask the rocks beneath, and the latter would probably be rotted to some distance beneath the surface by chemical and mechanical weathering. The ice would sweep away the loose material and also the rotted rock, and on the final disappearance of the ice the ice-worn rock, ground down by mechanical action alone, would be fresh, and, owing to the peculiar effects of glacial erosion, might resist the influence of weather for some time after the disappearance of the ice, leaving tracts of bare rock devoid of soil for considerable periods.

The ice passing over the rocks probably tears large blocks away along divisional planes, but it also rounds, scratches, and polishes the rocks, converting them into *roches moutonnées*, which are usually rounded in the direction from which the ice has come, being rough and rent on the opposite side, as shown diagrammatically in Fig. 36.

The rivers issuing from the ice carry glacial materials, which are deposited in much the same way as are the materials transported by ordinary rivers. These deposits of glacial rivers are termed fluvio-glacial deposits, and their composition will much resemble that of ordinary glacial deposits, allowing for the difference produced by the sorting action of the water.

As many areas, including a large portion of our own islands, have been subjected to the action of land-ice in past times, it is important for us to inquire what effects this has produced upon the country from an agricultural point of view.

Our upland valleys frequently show signs of vanished valley glaciers in the shape of terminal moraines of clayey and often sandy material crowded with boulders. These terminal moraines do not, as

FIG. 36.

ROCHE MOUTONNÉE.

The glacier moved from left to right.

a general rule, occupy large areas, and therefore need not be further considered.

Far different is the case with the boulder-clay, or *till*, as it is sometimes termed, which is widely spread over large tracts of some parts of our islands, and especially away from the centres of the upland regions, where, indeed, it may often have been removed by the ploughing action of subsequent valley glaciers.

The origin of this till is still under discussion. While most writers hold that the bulk of it is of terrestrial formation, having been deposited by ice-sheets during the recession of the ice, others believe it to be largely marine. This question, however, does not greatly concern us, for, as has been stated above, the composition of the terrestrial and marine boulder-clays will be very similar.

The *glacial drift* of the ice-sheets has been deposited in such a way that it often fills pre-existing inequalities in the ground, giving rise to a more uniform surface than that which originally existed, though the surface is often by no means flat, but diversified by those elongated hummocky mounds which are so often characteristic of a formerly glaciated area—mounds whose slopes are frequently so great that cultivation by lynchet has been frequently resorted to in their case. As a result of the filling up of inequalities, the thickness of the glacial drift varies rapidly in different spots. Where the drift has filled up an old valley it may be scores of feet in thickness, and in close proximity to this may be only a few feet deep. A knowledge of this is frequently important when searching for water in wells, and for other reasons.

The cultivable character of the boulder-drifts naturally differs greatly, according to the nature of the rocks from which the drift has been mainly derived. If the material has been largely derived from sandy rocks the mass of the drift will be sandy, if from clays clayey, and if from lime calcareous. As many drifts have, however, been formed from a variety of rocks, the composition of the inorganic materials of drift soils is likely to be more varied than that of soils formed *in situ* by weathering.

The extreme comminution of the particles of much of the boulder-clay and its pressure by overlying ice frequently render the clay extremely compact, so that it is difficult to remove it with the spade.

Again, the boulders often occur in very large numbers, and may be of great size, thus retarding agricultural operations, though, on the other hand, when removed from the soil, they may be often utilised for walling.

One very important character of glacial drift from the point of view of soil-formation is due to the fact that the disintegrating action of the ice is purely mechanical, and consequently the soluble constituents of the rocks from which the drift has been derived have not been removed. These soluble constituents may be taken up by the plants but slowly, and accordingly the drift soils may not yield such abundant crops as other soils at the outset, but, on the other hand, they may continue to furnish supplies of these soluble materials long after those of other soils have been exhausted.

CHAPTER XII

AGENTS OF TRANSPORT AND DEPOSITION

concluded

THE SEA

THE oceans are the great receptacles of sediment, which is partly carried into them by rivers and partly worn from the sea-margins as the result of marine denudation.

Marine denudation is caused by waves beating against the coast-line and hurling fragments of rock at the rocks of the coast. These fragments may be partly supplied by the agents of sub-aërial weathering and largely by the destructive action of the waves. On flat coasts the sea may gradually encroach on the land without formation of cliffs; but when the land is of some elevation cliffs may be produced by the battering of the waves, aided by weathering above the line of effective wave-action, and by the compression of air in cracks of the rock causing fragments to be burst off the cliffs. As the lower limit of wave-action is only a few fathoms beneath the surface, the result of continued marine denudation is the conversion of the destroyed land into a *plain of marine denudation* at a level determined by the downward limit of effective wave-action.

As marine denudation is often very destructive to valuable land along the coasts, it becomes of importance to check, when possible, the depredations of the sea, or, at any rate, to avoid any act which might tend to accelerate them. Parts of the east coast of England have been worn away by the sea at the rate of several feet per annum, and the sites of some ancient towns and villages are now far out at sea.

Study of the mode of transport of material shows how the waste of the coast is affected by the removal of material from the foreshore, as will be pointed out below.

We may consider the transporting action of the sea under two heads, namely (1) the carriage of material seaward, and (2) its transport along the shore.

Material is carried seaward as the result of the transporting action of off-shore currents. These currents are, like the waves, superficial, and when a particle of sediment has fallen to the lowest limit of effective onward transport, it will then fall vertically down to the sea-floor.

As the lighter materials will be carried further out from the coast before they have reached their lowest limit, the materials are sorted during their transport, and accordingly the mechanically suspended sediment is deposited somewhat in the manner shown in Fig. 37. The heavy pebbles are dropped close to the shore, forming a beach if the water be shallow; beyond this are sand-flats often laid dry at low water; further away the mud is deposited, and may be carried to a distance of 100 miles from the coast.

Beyond this, masses of limestone and silica are produced by the agency of organisms, which abstract the lime and silica from solution in the sea-water. In many cases the sea is clear of mechanical sediment much nearer to the shore-line, and organic deposits may then be formed at no great distance from the shore, as in some parts of the Irish Sea. At the junction of two kinds of deposit an intermixture is likely to occur, and thus tracts of sandy mud or loam, and muddy limestone or marl, are formed.

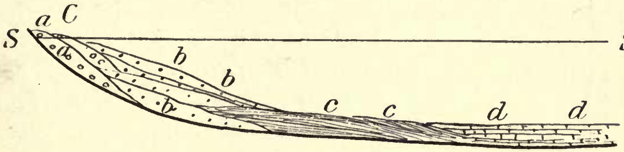


FIG. 37.

SECTION SHOWING TRANSPORT AND DEPOSIT OF SEDIMENT.

S S=Sea-level. *C*=Coast.
a=Pebbles. *b*=Sand. *c*=Mud. *d*=Lime.
Vertical scale much exaggerated.

After elevation of the sea-floor to form land, the sediments thus accumulated, and more or less consolidated in the course of ages, form the rocks of the earth's crust, the destruction of which gives rise to the varieties of soil described in Chapter IX.

The material which is deposited is not only that which is worn away by wave-action from the coastal margins, but also that brought down by rivers. In favourable circumstances the latter material is built up around the river mouth, forming a more or less fan-shaped delta, which gives rise to cultivable land of much the same character as that formed on the alluvial flats of river-valleys, or on the sites of filled-up lakes.

The on-shore transport of material is due to currents flowing obliquely toward the coast, and when striking it being deflected along the shore. Thus the prevalent south-west winds cause an eastward drifting of beach material along the south coast of England, while the tidal currents flowing southward along the east coast of England move the material held in suspension in the sea-water to the south. The material which has been removed from one part of the coast may thus be added to another part. Thus the fenland to the south of the Wash largely owes its existence to the deposit of marine silt which has been removed by denudation from the Yorkshire and North Lincolnshire coasts in the bay of the Wash, which is thus being gradually filled up; owing to the growth of marsh vegetation on the flat tract thus acquired, a new land eminently adapted to cultivation has been produced.

The conversion of flats of marine sediment in estuaries into fertile land tracts has already been carried out to a considerable extent in England; but there is yet much marsh land available for conversion into cultivable ground. In addition to the fenland and the estuaries around Morecambe Bay, parts of the Welsh coast have been rendered available for cultivation by artificial means. Toward the beginning of the last century about 7,000 acres of land were gained from the sea in the Portmadoc estuary at a cost of £100,000.

Many tracts of land which have been newly formed are the result of the joint action of river and sea, producing deposits which are partly of deltaic origin and partly due to the addition of marine sediment. Of this nature are the flats lying on the north side of Morecambe Bay, which have been recently reclaimed and converted into arable land.

In other parts of the world very extensive tracts of cultivable land have been produced by one or other of these actions, or by a combination of the two. Special mention may be made of the tracts along the north coast of the Adriatic, which are largely due to the partial filling up of that sea by the sediment which is borne down from the northern slopes of the Alps by the rivers of Northern Italy.

A very slight elevation of the land or lowering of the sea may give rise to the formation of considerable tracts of cultivable land, not differing very widely in their nature from those which have been above described. The great coastal plain which extends with varying width along the east side of the United States has been under water at no distant date, and by earth-movement has been converted into land.

On a smaller scale this has taken place in Britain. In many parts of our country raised beaches are found at varying heights above sea-level, and they are often flanked by flat strips of land covered by marine deposits, which are frequently of a cultivable nature. These former sea-floors may be well observed in several parts of Scotland, as, for instance, around the estuary of the Clyde, where they are often backed by old sea-cliffs.

Reference was made above to the importance of studying on-shore transport of sediment in order to prevent the destruction of land. It is not always consoling to know that the material robbed from one place is added to another, even if the addition be utilised for purposes of cultivation elsewhere. Now, it has been ascertained that the beaches along coast-lines, when sufficiently developed, act as breakwaters, preventing or checking the destruction of the land

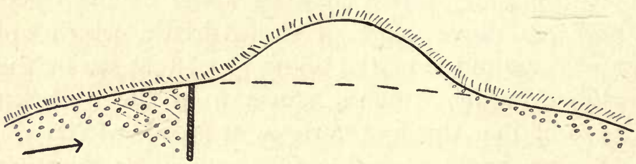


FIG. 38.

PLAN OF SHORE, SHOWING EFFECT OF GROYNE.

The continuous line with oblique lines above indicates present position of cliff.

The dotted line shows former position of cliff on lee side of groyne.

The round marks represent shingle.

The arrow shows direction of movement of beach material.

behind. If a groyne be constructed, as shown in plan in Fig. 38, the beach material will accumulate on the windward side of the groyne, and will be washed away from the lee side, thus laying bare a tract of coast; the sea is therefore enabled to make further inroads and to wear away the portion of the land which extended to the broken line. Construction of groynes should therefore be avoided if there is risk of destruction of land thereby. Destructive effect may also be produced by the excessive cartage of beach material for use elsewhere.

CHAPTER XIII

EARTH-MOVEMENTS, VOLCANOES, AND METAMORPHISM

THE effect of denudation would be to reduce all lands below the sea-level. The destructive action of the denuding agents is, however, counter-balanced by certain changes which are generally maintained to be due to the loss of heat from the earth's interior.

The interior of the earth as it gives off heat is believed to contract, and as the shrinking interior diminishes in size, the outer crust must adapt itself to the changed conditions by folding or fracture, or by both. This would give rise to the relative elevation of some parts of the earth's surface as compared with others, and therefore these movements are usually referred to as movements of elevation and depression.

New land might emerge from the sea as the result of lowering of the sea-floor, and accordingly of the ocean waters; or by uplift of the land above the waters.

That movement of the land does occur is abundantly evidenced in regions which are affected by earthquakes, for tracts of these regions are often permanently raised or lowered by earthquakes with respect to the surrounding tracts.

It is generally believed that many earthquakes are mere episodes in long periods of tranquil earth-movement—sudden jars due to snapping of the rocks beneath the surface.

Be this as it may, the fact that earth-movement has taken place in past times is fully proved by the existence of rock-strata in which the planes of stratification, once horizontal, are inclined at various angles, and in some cases are vertical or even overturned.

To the student of agriculture the causes of the tilting of these strata are unimportant; and we need not pursue the subject of earth-movement further than to state that the most evident foldings of the strata are usually found in mountain regions or among the denuded stumps of ancient mountain-systems, while plateaux and plains are frequently occupied by strata which are nearly or quite horizontal.

The study of the effects of inclination of the strata is, on the contrary, most important, and a special chapter must be devoted to consideration of the lie of the strata and the manner in which folds and fractures affect the stratified rocks.

VOLCANOES.—The fissures which are produced as one of the results of earth-movement may form lines of weakness, through which matter from the interior of the earth is brought to the surface in a molten condition or in a fragmental state. The molten rock and the fragments of once molten material accumulate around the vents through which they are forced, to form volcanoes, which are merely accumulations of this ejected material covering the earth's surface, as it existed before their emission. A volcano differs from an ordinary hill, not only in the character of its component rocks, but also in its mode of origin;

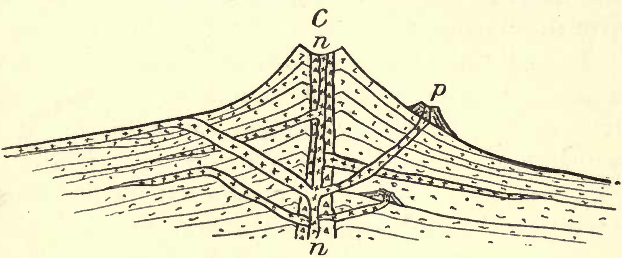


FIG. 39.

SECTION THROUGH A VOLCANO.

Rock forced in or poured out in molten state.

Fragmental rocks (volcanic ashes).

Coarse volcanic agglomerate in neck.

C=Crater. *n n*=Neck. *p*=Parasitic cone.

it is a hill of accumulation, not one of upheaval worn into shape by denudation.

Fig. 39, which is a diagrammatic section across a volcano, will give the reader a general idea of the character of a normal volcano.

The nature of the soil derived from volcanic rocks varies considerably, as the rocks themselves are of very varied composition.

As the rocks brought out from the earth's interior have undergone no weathering action prior to emission, their soluble constituents have not been leached out, and they usually contain a considerable quantity of alkali, often a potash salt.

Again, the fragmental rocks which are thrown out as volcanic ashes and volcanic dust are usually very porous and permeable; accordingly they are readily decomposed by the agents of weathering, and thus give rise to soils.

The soils of volcanic regions are consequently often extremely fertile, so much so, indeed, in many cases that a considerable population engaged largely in agricultural pursuits is often found existing on the slopes of active volcanoes, undeterred by the catastrophes which have happened in former times.

Volcanic rocks are frequently found associated with the sediments of ancient date. The Snowdonian heights, the group of Scawfell in Cumberland, and many of the hills of the Central Valley of Scotland are composed of rocks of volcanic origin of very ancient date, and these rocks doubtless have an influence on the composition of the overlying soil, though the steep slopes of many of the hills composed of volcanic rock, which owing to their hardness have resisted denudation while the softer surrounding rocks have been worn away, render them unfit for tillage, and cause them to be utilised chiefly for sheep pasture.

METAMORPHISM.— Reference has already been made to the fact that rocks undergo considerable changes after their formation, and when these changes are very great the rocks which have undergone alteration are spoken of as metamorphic rocks.

Metamorphism may be brought about by percolation of heated water through rocks; by the heating of the rocks owing to the injection of molten rock among them; and lastly by the pressure exerted by great masses of overlying rock, or in a lateral direction during earth-movements. Fresh divisional planes are thus produced in some rocks, for instance, the cleavage-planes, which are specially found in

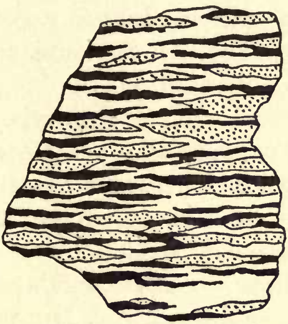


FIG. 40.

PIECE OF SCHIST.

Dotted part = Felspar.
White part = Quartz. Black part = Mica.

muds which have undergone great lateral pressure; these, owing to the possession of this property of cleavage along planes often inclined at high angles to the original planes of bedding, are known as slates.

In addition to the physical changes which are brought about as the result of metamorphic action, many important chemical changes also occur, and over many areas the rocks have become completely crystalline, and have entirely lost their original texture. The crystals are usually arranged in layers or *folia* lying parallel to one another, and along these layers the rocks are often readily split. Such *foliated* crystalline rocks are known as crystalline *schists.*[1] In Fig. 40 a representation of a fragment of crystalline schist composed of three minerals—felspar, mica, and quartz—is given.

The crystalline schists often occupy vast areas of country. In our own islands a great part of the North-west Highlands of Scotland, and of Donegal in Ireland, is mainly occupied by these rocks. They are widely spread over Scandinavia and parts of Bavaria and Bohemia, and occupy a considerable portion of Brazil and great tracts in Canada.

The soils which cover them are very varied in character, for the composition of the schists varies enormously. They usually contain a considerable proportion of soluble material, but it is not in all cases easily extracted from the rocks, and accordingly whereas many schists give rise to a very fertile soil there are other cases where the ground occupied by these schists is peculiarly barren, the bare rock occupying the surface of the ground over wide tracts of country.

[1] See Chap. VII, p. 73.

Section III

GEOLOGICAL SURVEYING

CHAPTER XIV

GEOLOGICAL MAPS AND SECTIONS

MANY things may be represented upon geological maps, but two kinds of geological maps are of particular importance to the student of agriculture, viz. that kind which exhibits the distribution and variations in the characters of the superficial accumulations which lie between the solid rocks and the soil (if the latter be present), and that which exhibits the distribution and variations in the characters of the solid rocks.

The Geological Survey of Great Britain and Ireland publishes these two kinds of maps, and it is desirable that the student should be thoroughly conversant with the significance of the various records which are entered upon these maps.

It will be convenient to commence with a description of the maps which represent the distribution of the solid rocks.

As a large part of the earth's surface[1] is occupied by stratified deposits, the boundaries between the different divisions of these rocks tend to coincide

[1] The earth's surface is spoken of here as though the superficial deposits did not exist. A geological map of the solid rocks represents what would be seen if these superficial accumulations were stripped off.

with the appearance of planes of stratification upon the surface.

If the strata had not been disturbed, as described in the last chapter, they would occur in layers parallel with the surface of the earth; but owing to disturbance and denudation the edges of the strata frequently abut against the surface, and the strata themselves slant downward beneath the surface.

We must now consider various points connected with the inclination of strata and the terminology which is applied thereto.

Inclined strata are said to *dip*. They dip downward beneath the surface of the earth. The angle of *true dip*, which is usually spoken of simply as the *dip*, is the greatest angle which the stratum makes with a horizontal plane. If a sheet of paper be held on the slope, and considered to represent a bed, the greatest angle to the horizon would be that measured between a line down which a drop of water would flow on the paper and a horizontal line drawn immediately under it. The direction in which the line formed by the water-drop slopes downward is the direction of the true dip or, shortly, *direction of dip*.

In Fig. 41 the direction of the dip is shown by the arrow.

If a vertical cutting, such as a cliff or a railway cutting, exhibited inclined strata, and if the face of the cutting were in the direction of the dip, the true dip of the rocks would be exhibited in the cutting. If, however, the cutting extended in any direction not that of the true dip, or that at right angles to it, the beds would appear to be inclined; but the inclination would be less than that of the true dip, and the direction of this inclination would, of course, be different from that of the true dip. A dip which is not the true dip is spoken of as an *apparent dip*. Should the cutting be made at right angles to the direction of the true dip, the beds would appear to be horizontal as seen in the cutting, how-

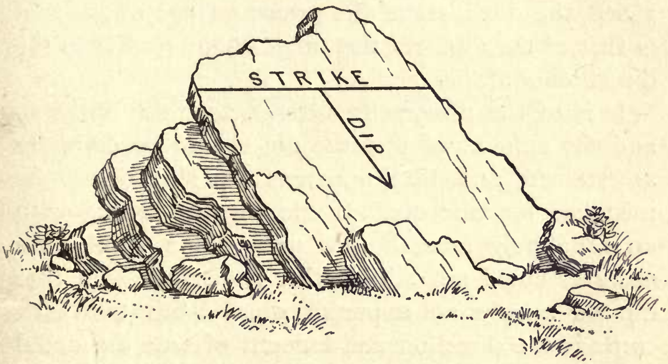


FIG. 41.

STRATA SHOWING DIP AND STRIKE.

ever high the actual inclination of the beds might be. This direction is spoken of as the direction of the *strike*. The *strike* of the beds is an imaginary horizontal straight line drawn at right angles to the direction of true dip of the beds. It is indicated by the thick black line ruled across the uppermost bed in Fig. 41.

The line of intersection of a plane of stratification with the earth's surface is known as the *outcrop* of the plane of stratification. The outcrop of a stratum is the appearance of the stratum at the surface, and in inclined strata the successive outcrops will form strips of varying width on the surface of the ground.

The outcrop, as will be explained presently, may or may not coincide with the direction of strike of the beds.

The case of a house-roof is often taken to illustrate dip and strike. If the slates be supposed to represent a bed, the direction of the greatest slope of the roof is that of the dip, and the ridge of the roof is in the direction of strike.

It is of the utmost importance that the direction and the amount of the true dip should be correctly ascertained, and that apparent dip should not be mistaken for true dip. If one vertical cutting with an absolutely smooth face were alone visible, the observer could not tell whether it displayed the true dip or merely an apparent dip. With two such cuttings the direction and amount of true dip could be calculated after observing the directions and amounts of apparent dip. This will be considered in the sequel. In nature, as the exposures of rocks are not usually on absolutely smooth faces, the true dip may be generally ascertained when the face of the cutting is not in the direction of true dip, owing to the surfaces of beds projecting slightly. In Fig. 42 the true dip is supposed to be seen in the section facing the reader. If the observer could only see the cliff which is shown in profile, he would see an apparent dip from a distance (or horizontal beds if the cliff were in the direction of strike), but could obtain the direction and amount of the true dip where the surfaces of the beds *b* and *c* are exposed at *x* and *y* respectively.

It is not always possible to distinguish between planes of stratification and other divisional planes traversing strata. In most cases the distinction is obvious, but in other cases much practice is needed to discriminate, and the student should never lose an opportunity of studying the features presented by planes of stratification and by other divisional planes.

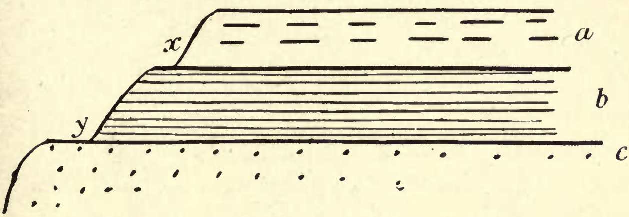


FIG. 42.

The inclination of strata is measured by an instrument known as the *clinometer*, of which there are many forms, most of these also carrying a compass which is required for ascertaining the direction of the dip of the strata. A useful form is represented in Fig. 43. A freely swinging pendulum is attached to the centre of a graduated circle. At the bottom of the instrument is placed a straight bar. If this bar be laid on a flat surface, the circle being held vertically, the pointer of the pendulum points to 0°, and if the bar be laid against a vertical surface, the pointer indicates 90°, if on a slope of 45°, the pointer shows 45°, and so on. When the true dip is known to be exhibited in a vertical cutting the amount of dip can be most readily ascertained by standing some way from the cutting and holding the instrument so that the bar lies parallel with the plane of stratification whose inclination is being determined. Should, however, the dip be taken on the surface of a bed, as that

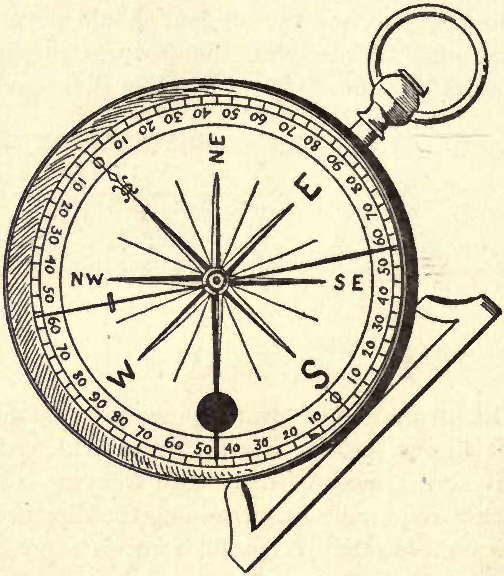


FIG. 43.
COMPASS-CLINOMETER.

surface may not be absolutely smooth, it is advisable to place a flat ruler on the bed, so that minor inequalities are avoided, and then to place the bar of the clinometer on the ruler. The direction of the true dip can then be ascertained by moving the clinometer (held so that the circle is vertical) until the highest angle which can be read off is obtained. That is the angle of true dip, and may be recorded.

A very convenient clinometer may be formed by having a graduated semicircle sunk into the face of a ruler, so that the pendulum may be shut in when the ruler is folded up. A small compass may be let in to another part of the ruler, and the observer is then supplied with measure, clinometer, and compass in one instrument.

The reader is no doubt aware that the compass in Britain does not point to the true north, but somewhat to the west of it. The amount of deviation from true north varies at different times. At the present time the compass in Britain points about 16° west of true north. This is magnetic north, but observations of direction should in all cases be recorded with reference to the true north, and not to the magnetic north.

The direction of the dip is usually indicated on a geological map by an arrow, the head of which points to the direction of the dip, the actual point of the arrow coinciding with the point at which the observation is made, while the amount of dip is indicated by figures placed near the head: thus a sign ↙45 indicates that the bed is dipping in a south-westerly direction at an angle of 45°.

We may now consider the nature of the folds into which inclined beds are thrown, and it is convenient to refer these folds to ideal cases to which they approximate more or less closely when they do not actually agree with them. When strata are thrown into an arch, as represented in section in Fig. 44, the arrangement is spoken of as an *anticlinal fold* or *anticline.* With this arrangement the beds dip away on either side from a common axis. If the anticline be regarded as a semicylinder, the axis of the anticline is the line which forms the axis of the cylinder. The anticline may be symmetrical, as in Fig. 44 (*a*), or asymmetrical, with one side steeper than the other, as in Fig. 44 (*b*).

If the anticline be folded around a horizontal axis, and its top denuded to a plane surface, the beds will crop out as parallel strips, as shown in Fig. 45 (A). If, however, the axis of the anticline be itself inclined, and the system be denuded to a level surface, the

FIG. 44.
SECTIONS OF ANTICLINAL FOLDS.

beds will crop out with V-shaped outcrops, as shown in Fig. 45 (B); the apices of the V's will in this case point in the direction in which the axis is dipping. This is of considerable practical import, and many serious errors in the search for strata have been made by want of recognition of the fact that the axis is sometimes inclined.

When strata are thrown into a trough, as shown in Fig. 46, the arrangement is spoken of as a *synclinal* fold or *syncline.* This may also be symmetrical or asymmetrical. The outcrop of the beds of a syncline will be like those represented in the case of the anticline, except that the arrows in the map will be directed towards the axis, and the newest

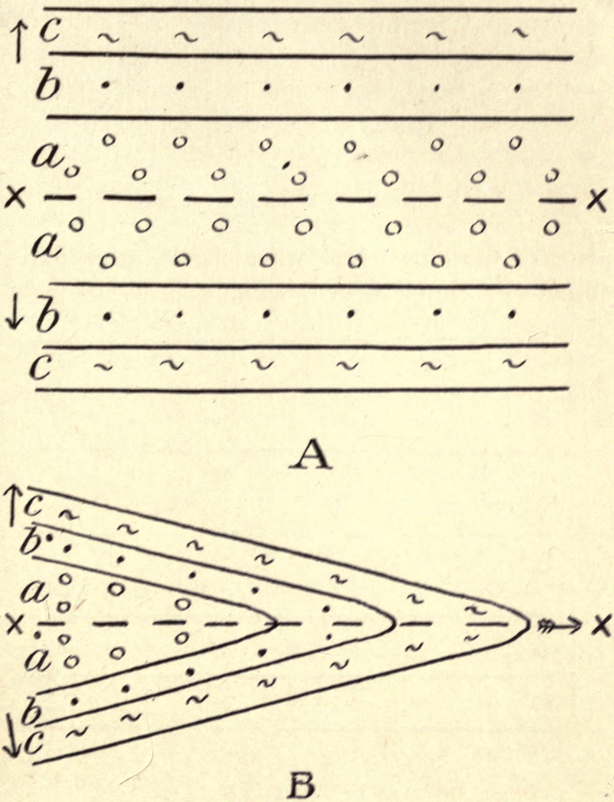


FIG. 45.

PLANS OF ANTICLINAL FOLDS.

A. With horizontal axis. B. With inclined axis.
× × = Direction of axis.
The unfeathered arrows show directions of dip of beds.
The feathered arrow in B shows direction of dip of axis.

bed of the system will crop out above the axis in

FIG. 46.

SECTIONS OF SYNCLINAL FOLDS.

place of the oldest bed, which is the case with the anticline. This is shown in Fig. 47.

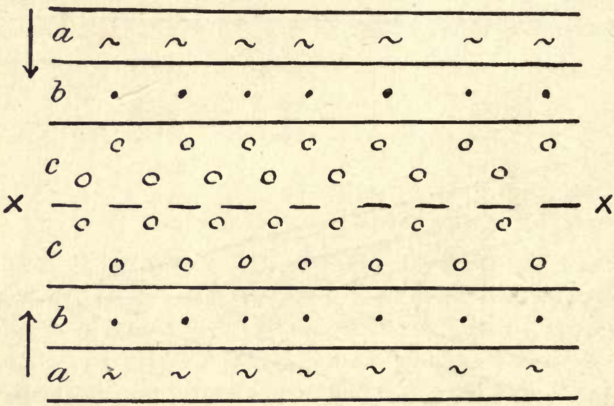


FIG. 47.

PLAN OF SYNCLINAL FOLD.

× × = Direction of axis.
The arrows show directions of dip of the beds.

When the axis of the syncline is inclined, the V-shaped outcrops will be arranged with the points of the V's in a direction opposite to that in which the axis is dipping.

In Fig. 48 (left-hand section) is represented a fold which consists of anticline with syncline. It will be seen that one part of the fold × is common to the two; this is known as the *middle limb* or *septum.* If the middle limb possesses a marked inclination, and the other limbs are practically horizontal, as shown in Fig. 48 (right-hand section), the arrangement is spoken of as a *monoclinal* fold or *monocline.*

If lateral pressure be applied to the rocks, as arranged in Fig. 48, so that the middle limb rotates around its central point ×, this limb will become vertical, and finally turned over, so that the beds

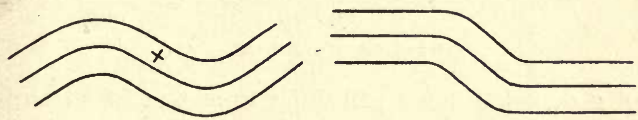


FIG. 48.

which were originally lower in it now become uppermost. These beds are said to be *inverted,* and the arrangement is known as an *overfold.* An overfold is represented in section in Fig. 49.

It will be observed that the older bed *b* is now above *a* in the middle limb, though it is beneath *a* in the other limbs. Overfolds are often found in mountain regions, or in areas which represent the denuded stumps of mountain regions, and the beds of the middle limbs are frequently thinner than the corresponding beds of the other limbs, owing to stretching.

If strata, instead of dipping away from an axial line as in the case of an anticline, dip from a point, the arrangement is spoken of as a *dome*. The section across a dome will resemble that taken across an anticline at right angles to its axis, but the plan

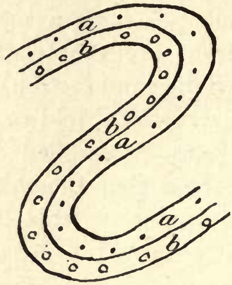
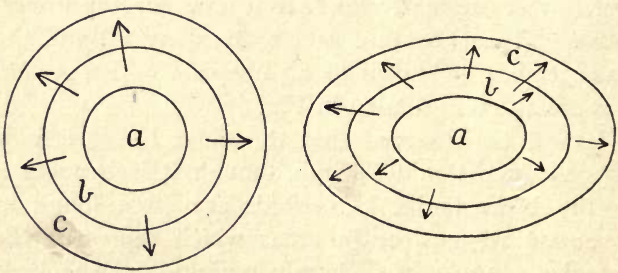


FIG. 49.

SECTION OF OVERFOLDED BEDS.

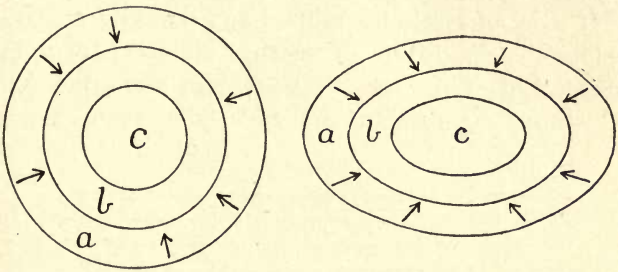
of a denuded dome will differ from that of an anticline. If the dome were absolutely symmetrical, the beds would crop out on a horizontal surface as con-



A FIG. 50. B

centric circles, as shown in plan in Fig. 50 (A), though, as the majority of domes are not symmetrical, it is more common for the outcrops to approach the form of ellipses, as represented in plan in Fig. 50 (B). Beds folded in the form of a dome are sometimes spoken of as having a *quaquaversal* dip: this term is, however, but little used at the present day.

A *basin* bears the same relationship to a dome as a syncline bears to an anticline. In it the beds dip



A FIG. 51. B

toward a common centre. The section across a basin is therefore similar to that across a syncline at right angles to its axis, while in plan the basin appears as seen in Fig. 51, where A represents a symmetrical, and B an asymmetrical basin.

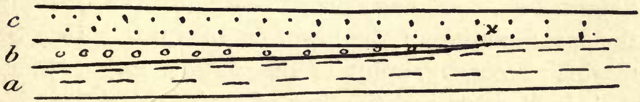


FIG. 52.

SECTION OF OVERLAP.

Two other arrangements of *strata* remain to be noticed. They are respectively termed *overlap* and *unconformability*, or, more shortly, *unconformity*.

Overlap is represented in Fig. 52. If the supply of sediment during the formation of a stratum *b* was not carried beyond ×, whereas the supply was carried beyond it during the deposition of the underlying stratum *a* and the overlying stratum *c*, the stratum *c* is said to overlap the stratum *b*. The disappearance of a stratum of economic importance by overlap must always be reckoned with.

If a set of strata be uplifted and partially denuded before the deposition of another set upon them, the lowest bed of the latter set will rest upon the edges of various members of the underlying set, as shown

FIG. 53.

SECTION OF UNCONFORMITY.

a = Older group of strata. *b* = Newer group of strata.
PP = Plane of unconformity.

in Fig. 53. This is an unconformity, and it implies depression of an area beneath the sea-floor during the accumulation of the lower set of strata if they be marine; secondly, uplift of these strata to give them their inclination and to allow of their partial denudation; and thirdly, fresh depression to allow of the accumulation of the newer set.

There must, of course, be subsequent upheaval to cause the appearance of the second set above the water, and to allow of their partial denudation, if the older set be exposed at the surface, as is often the case in nature.

FIG. 54.

PLAN OF NORTHUMBRIAN, AND YORKS DERBY AND NOTTS COALFIELDS.

Showing unconformity between Permian and Carboniferous Beds.

The Permian beds on the east are represented by broken lines.

The crosses represent coal measures.

The dots represent Millstone grit.

The vertical lines represent Lower Carboniferous Beds.

The arrows show directions of dip.

Unconformity may be detected in plan as well as in section, owing to the difference of strike of the two sets of beds, as shown in the map, Fig. 54, which represents a part of the North of England, including the Northumberland and Yorkshire coalfields and adjoining country, where the Permian strata rest unconformably upon the upheaved edges of the more ancient Carboniferous strata. It will be noticed that the planes of stratification of the newer system of beds tend to possess a general parallelism with

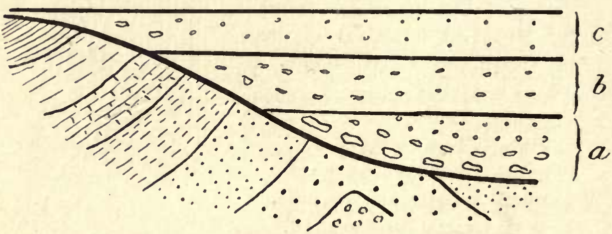


FIG. 55.

SECTION OF UNCONFORMABLE OVERLAP.

the plane of unconformity, whereas the planes of stratification of the rocks of the older system abut against it.

Unconformity is often accompanied by overlap, owing to the deposition of newer strata against a subsiding surface of sloping land. This is represented in Fig. 55, where the newer strata *a*, *b*, *c* rest on the folded and eroded older strata, and in addition *b* overlaps *a* and *c* overlaps *b*. This is spoken of as unconformable overlap.

Numerous local unconformities on a small scale are frequently formed in beds deposited in shallow water, owing to variations in the velocity and the direction of currents of water. The currents may at one time erode and at another deposit. The strata are accordingly inclined at various angles, and this is especially the case with *stratula*[1] and *laminae*, as represented in Fig. 56. This arrangement of the deposits is spoken of as *False Bedding*, or sometimes as *Current Bedding* or *Diagonal Stratification*, though

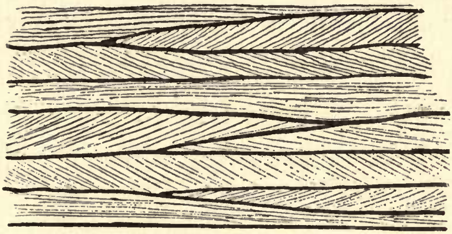


FIG. 56.

DIAGRAM OF FALSE BEDDING.

the first of these is the term which is usually adopted.

VARIATION IN THE WIDTH OF OUTCROP OF STRATA.—The width of the outcrop of strata depends upon (i) their thickness, (ii) their angle of dip, (iii) inequalities in the level of the surface of the ground. If the ground be horizontal, and the dip of the bed constant in amount and direction, any variation in the width of outcrop of that bed is dependent upon variation in the thickness of the bed. The outcrop of a bed naturally becomes narrower as the bed thins out. Many variations in the width

[1] Stratula are thin strata.

of outcrop occur, however, when the beds are not thinning out, and these are due to variations in the dip or in the surface of the ground. On a level surface the outcrop of a horizontal stratum would extend as far as the deposit existed. If the surface remained level and the stratum were vertical, the width of the outcrop would be equal to the thickness of the bed. If the stratum were inclined and the ground level, the width of the outcrop would be greater than the thickness of the bed, and would increase in amount as the dip became less. This is

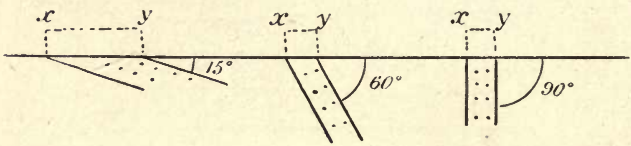


FIG. 57.

SECTION SHOWING VARIATIONS IN WIDTH OF OUTCROPS OWING TO DIFFERENT INCLINATIONS OF BEDS.

illustrated in Fig. 57, which shows three beds of similar thickness: one vertical, another dipping at an angle of 15°, and the other at an angle of 60°; the width of outcrop is represented in each case by the distance from x to y.

The variations due to inequalities of the ground are not quite so simple when shown upon a map. When a bed is horizontal, or dips in a direction opposite to that of the slope of the ground, the outcrop becomes narrower as the ground becomes steeper, until, when the ground forms a perpendicular precipice, the outcrop would be represented on a map as a line. This is illustrated in section in Fig. 58, which exhibits two beds of equal thickness; one crops out on a highly inclined surface, the other on a surface which slopes more gently. The width of outcrop as seen on the map is indicated in each case by the horizontal dotted lines *xy* which join the two vertical lines drawn from the points where the planes of stratification defining the upper and lower surfaces of the beds cut the ground along the line of section.

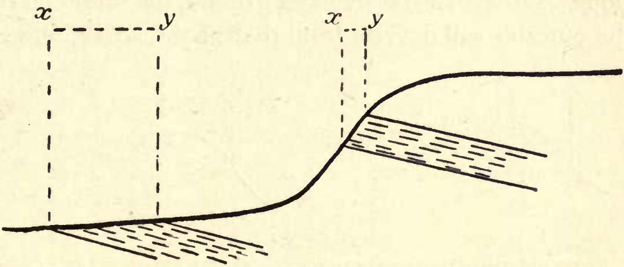


FIG. 58.

SECTION SHOWING VARIATIONS IN WIDTH OF OUTCROP (*xy*) OF BED WITH VARYING SLOPE OF GROUND.

Should a bed in any part of its outcrop dip in the same direction as the slope of the ground, the width of outcrop may suddenly increase, as shown in Fig. 59, where the left figure exhibits a bed whose dip is in a direction opposite to that of the slope, while the right figure exhibits a bed of similar thickness, which, over a considerable width of its outcrop, is inclined in the same direction as that in which the ground slopes. Sudden and marked changes in the width of outcrop may be suspected to be due to this cause, rather than to sudden increase in the thickness of the bed.

Sinuosities of Outcrop on Uneven Ground. —Strike has been defined as a horizontal straight line at right angles to the direction of the dip of a bed. Accordingly, on a horizontal surface the outcrop of a plane of stratification will be along its line of strike, and a bed will crop out in the direction of its strike. The same thing would occur on sloping ground, if the strike of the strata were at right angles to the angle of greatest inclination of the slope. Otherwise, on inclined ground, the direction of the outcrop will deviate from that of the strike, unless

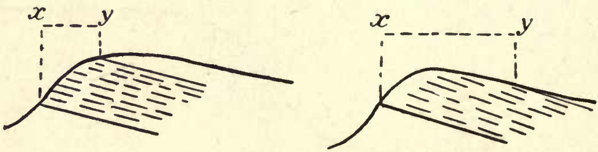


Fig. 59.

SECTIONS SHOWING VARIATIONS IN WIDTH OF OUTCROP ($x y$) OF BED WITH SLOPING GROUND.

the beds be absolutely vertical. In the case of vertical beds the outcrop as exhibited on a map will run in the direction of strike.

If the student will examine a contoured map of a region occupied by hill and valley, he will notice that the contour lines (each of which is drawn through points having the same vertical height above the sea-level) form U- or V-shaped lines, the apices of which point towards the heads of the valleys and in the opposite direction on the intervening ridges. It is obvious that horizontal beds would crop out in the same way, hence :—

1. *The outcrops of horizontal beds follow the contour*

lines.—In this case the observer, walking towards the head of the valley, will constantly pass from older to newer beds.

Now let us imagine that the beds instead of being horizontal are very slightly tilted, so that they possess a dip; and let that dip be towards the head of the valley. It is obvious that this very slight tilt will not produce a very great change in the direction of the outcrop, and the apex of the V formed by the outcrop of each bed will still point up the valley, though the outcrops will no longer follow the contour lines, the apices of the V's now forming a more obtuse angle than that of the contour lines. As the amount of dip is increased, the angle of the apex will become more and more obtuse, until at length, when the bed is vertical, there will be no angle; but the bed, as already stated, will crop out along a straight line parallel to its strike. Therefore:—

2. *When a bed dips towards the head of a valley, the apex of the* V*-shaped outcrop points up the valley.*—This is shown in Fig. 60 (right-hand figure), which is a representation of one of Sopwith's models made to illustrate the mode of outcrop of beds, representation of two other models illustrating the cases to be described being given in the other portions of the figure. In the case represented by Fig. 60 (right-hand figure) also, the observer reaches newer beds as he proceeds towards the head of the valley.

When a bed dips down the valley the direction of the apex of the V depends upon the relationship between the angle of dip of the strata and the angle of inclination of the valley floor.

3. *When the bed dips down the valley at a greater angle than that of the valley floor, the apex of the* V *points down the valley.* This is seen in the model represented in Fig. 60 (central figure). In this case the observer passes from newer to older beds as he proceeds up the valley.

4. *When the bed dips down the valley at a less angle than that of the valley floor, the apex of the* V

FIG. 60.

SOPWITH'S MODELS.

On right-hand side the beds are dipping *up* valley.
In centre the beds are dipping *down* valley at a *greater* angle than slope of valley floor.
On left-hand side the beds are dipping *down* valley at *less* angle than that of valley floor.
Figures give amount of angle of dip.

points up the valley (see left-hand figure). If we tilt the model so that the valley floor is horizontal, and proceed with the tilt so that the valley now slopes very slightly in the opposite direction, as the angle of dip of the bed is greater than the original angle of the valley, the dip of the bed would remain in its original direction, and as the valley slope is now reversed, the bed would be dipping up the valley, and the arrangement would be the same as in case 2.

In case 4, as in cases 1 and 2, the observer passes from older to newer beds when proceeding up the valley.[1]

From these considerations it is obvious that when the apex of the V is pointing down the valley, the direction of dip is indicated, and accordingly a student, when examining a map of a country diversified by ridge and valley, noting that the apices of the V's are directed down the valley, knows that the dip is seaward rather than towards the interior of the country, whereas if the apices of the V's are directed up valley, he cannot tell from that alone whether the beds are dipping seaward or in the contrary direction.

Should the dip be in the actual direction of the valley floors and ridge-summits, the outcrop of the beds will be on the whole at right angles to that direction, whereas, if the dip be oblique, the outcrop will also be oblique, as shown in Fig. 61 (A and B).

As in most countries the vertical heights are slight when compared with horizontal distances, the general direction of outcrop will correspond with the general direction of strike of the beds, for, when a considerable distance is traversed, the zigzags on either side of the direction of strike do not depart very widely from that line.

The sinuosities of outcrop, also, are likely to be greater when the beds approximate to the horizontal, and smaller when they approach the vertical.

As these sinuosities increase, portions of promontories of newer rocks may be severed from the

[1] It is assumed that the beds are not inverted in these cases.

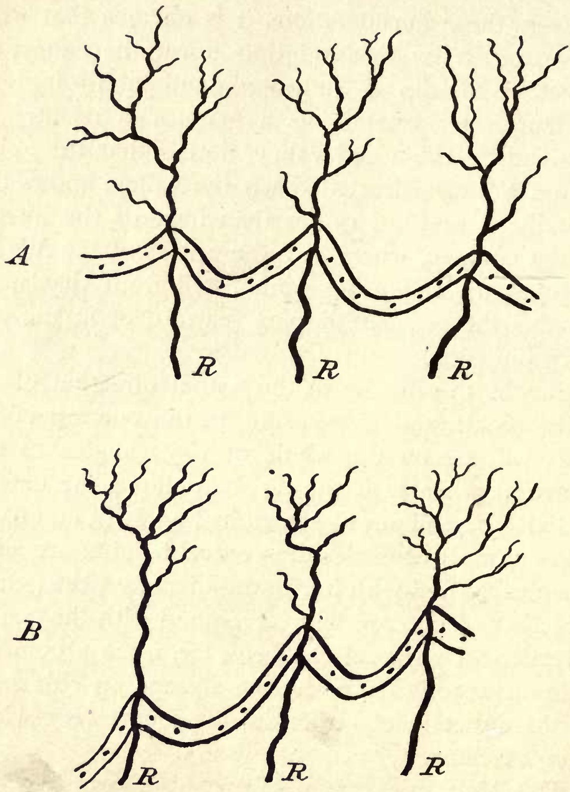


FIG. 61.

PLAN OF OUTCROP OF STRATUM.

A. At right angles } to slope of valley floors.
B. Obliquely } to slope of valley floors.

R R R = Rivers.

main mass, as shown in Fig. 62. In this case islands (as it were) of newer rock are entirely surrounded by older rock. These are termed *outliers.*

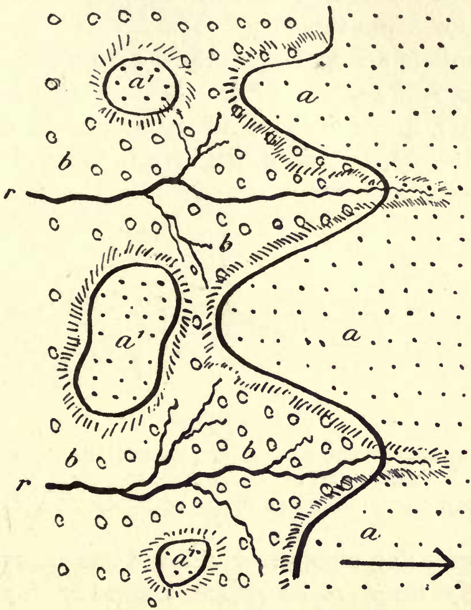


Fig. 62.

PLAN OF ESCARPMENT AND OUTLIERS.

The outliers, *a'*, of the bed, represented by dots, were once continuous with the main mass, and have since been severed by denudation, so that each is now surrounded by the bed, *b* (represented by circles). The arrow shows direction of dip. *r r* = Rivers.

Outliers usually, though by no means necessarily, occur on hill-summits; should they not, they must be the lower portions of basin-shaped folds. In many cases the outlier occupies a hilltop and at the same time forms the base of a geological basin, as shown in Fig. 63, for the rocks are here in a position of comparative stability, and the outlier is likely to endure for some time.

As outliers are so frequently due to the severance of portions of peninsula-like masses of beds from the main mass, they are likely to be far more numerous in the case of slightly inclined strata than of highly tilted beds, and they are accordingly frequently

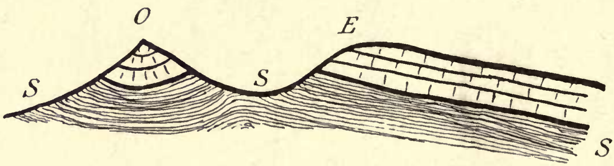


FIG. 63.

SECTION SHOWING ESCARPMENT, *E*, AND OUTLIER, *O*, OF HARD BEDS RESTING ON SOFTER BEDS, *SS*, THE BED OF THE OUTLIER BEING FOLDED INTO A BASIN.

found extending along those sides of the escarpments of gently tilted rocks which are away from the direction of dip. For instance, to the north-west of the escarpment of the lower oolites, which runs across England from north-east to south-west, a large number of outliers of these oolites are found resting upon the strata which underlie them.

It may be noted here that an *inlier* is a mass of older beds surrounded by newer strata. An inlier rarely occurs in nature save when the rocks have been folded into a dome or an anticline, or faulted along a fracture lying athwart a valley. Inliers are likely to be found towards valley bottoms, or where old rocks are unconformably succeeded by newer ones occupying low ground.

FAULTS.—It has been seen that, as the result of earth-movements, beds may be folded. If the beds are too rigid to bend, they may snap across, and one set of beds may be carried up or down so as to abut against another set. The beds are then said to be *faulted*. Fig. 64 is a vertical section showing

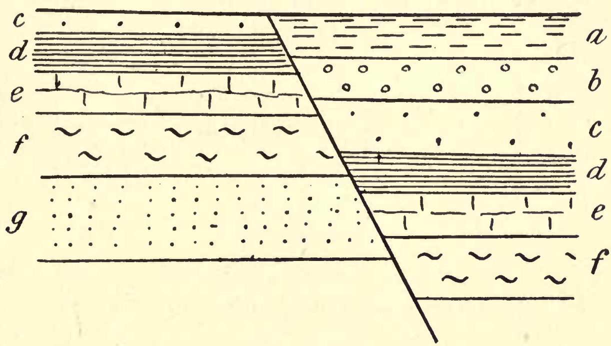


FIG. 64.

SECTION OF FAULT.

beds affected by a *fault*. The fissure may be vertical, or may be inclined. An inclined fault-fissure is said to hade (and is not spoken of as dipping); the angle of hade is measured from a vertical and not from a horizontal plane.[1]

[1] The terms "high hade" and "low hade" are used somewhat vaguely. Some writers seem to consider that a fissure approaching the horizontal possesses a high hade, while others use the term for one approaching the vertical! The student will do well, therefore, to speak of fault-planes as approaching the vertical or the horizontal respectively, and to discard the terms "high hade" and "low hade."

In Figure 64 any particular bed, as *c*, is abutting against the fault-plane at a lower level on the right-hand side of the diagram than on the left-hand side. The beds on the right-hand side are accordingly spoken of as being on the *downthrow* side; those on the left are on the *upthrow* side of the fault. These expressions do not necessarily imply that the right-hand side has been moved down and the left-hand side moved up. One side may have been stationary, or the two sides may have been actually moved in

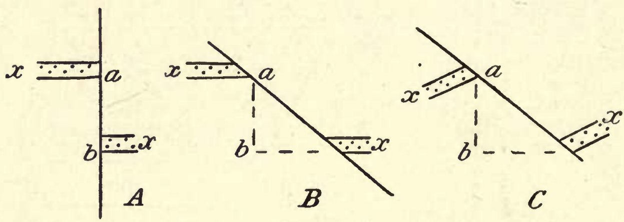


FIG. 65.

SECTIONS SHOWING THROW OF FAULTS.

the same direction, but one of them to a greater extent than the other.

The *throw* of a fault is the amount of movement which has taken place as measured along a vertical line. In Fig. 65 three vertical sections are drawn. The first of these, A, shows a bed *x*, which is there horizontal, affected by a vertical fault. In B the fault-fissure is inclined, and in C both the fissure and the bed are inclined. On the scale of the section, the amount of throw in each case is represented by $\frac{3}{8}$ inch. In the cases B and C the throw is measured along a vertical line, drawn from the point where one surface (say, the lower) of a particular stratum cuts the fault-plane on the upthrow side to the point where a horizontal line drawn from the point where that surface of the same bed on the downthrow side of the fault cuts this vertical line. The amount of throw in each case of the diagram is therefore represented by the distance *ab*.

In Fig. 66 representation of two faults with inclined fissures is given. In A, a tract of barren ground, having the width *xy*, exists where a vertical

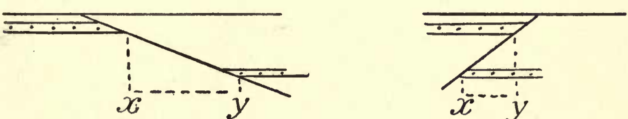


FIG. 66.

A. NORMAL } FAULT.
B. REVERSED }

xy=Width of barren ground in A, and width of ground where stratum may be twice pierced by a vertical shaft in B.

shaft sunk from the surface would nowhere pierce the stratum represented in the section. In B a tract of nearly similar width is not barren, but a vertical shaft would sink through the same stratum twice. The former fault is termed *normal*, the latter *reversed*. A reversed fault, then, is one in which at some point a vertical shaft can be sunk through the same stratum twice, and that can never be done with a normal fault.[1] It will be well to confine our account of

[1] *i.e.* as the result of faulting. If the beds were violently folded in addition, it might be possible to sink such a shaft.

normal and reversed faults to this brief description, and not to attempt definitions of these faults, as such definitions are frequently misleading.

Reversed faults are sometimes spoken of as thrust-planes, though some writers seem to limit the term to those reversed faults which possess a fissure approaching to the horizontal.

Folding sometimes occurs to some extent before faulting takes place, and accordingly we have each kind of fold represented by a fault. An

A B C D

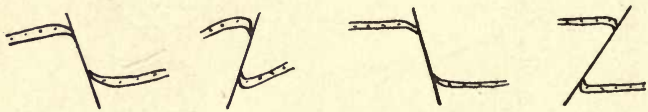


FIG. 67.

A. NORMAL } FAULT.
B. REVERSED }

C. NORMAL } MONOCLINAL FAULT.
D. REVERSED }

ordinary anticlinal and synclinal fold may be replaced by a normal fault, an overfold by a reversed fault, and a monoclinal fold by a monoclinal fault. The relics of the folds are retained after faulting has occurred, as hooked portions of the strata, which have the characters shown in the different sections represented in Fig. 67. In a large number of cases, however, no appreciable folding of the strata has taken place prior to faulting, and there is in those cases no change of dip near the line of fracture.

No important fault can exist in an area unaccompanied by other faults. It necessitates the existence of two curved fractures or three straight fractures to cause a marked displacement of the beds. Accordingly when one fault has been discovered in an area, others may be confidently sought.

It has been noticed in Chapter VI. that the principal joints which affect stratified rocks tend to run in two

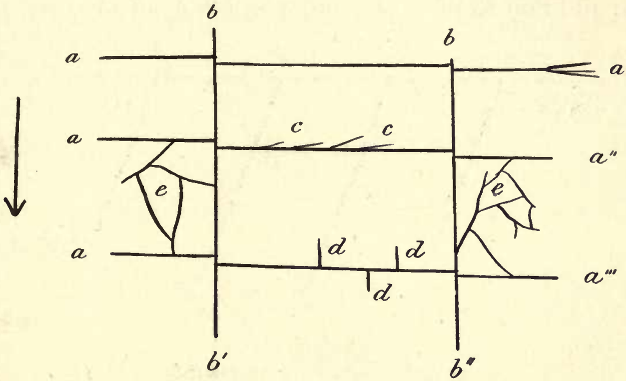


FIG. 68.

PLAN OF FAULT-FISSURES.

The arrow shows the direction of dip of the beds.

directions, which are parallel to those of dip and strike respectively. Accordingly the principal faults, the fissures of which are merely joints along which displacement has taken place, are apt to follow the same directions, and are spoken of as dip-faults and strike-faults. These faults are represented in plan in Fig. 68, where *a a'*, *a a''*, and *a a'''* are strike-faults, while *b b'* and *b b''* are dip-faults. These and other faults, before dying out laterally, often split into two or more minor faults, as shown at *a'*. From the sides of the major faults subsidiary fractures often extend with courses oblique to that of the main fissure, as represented at *c c*, on the north side of the fissure *a a''*, or offsets may extend at right angles to the main fault, as shown on each side of the fault *a a'''*, at *d*, *d*. These lateral faults have a throw which diminishes as they recede from the main fracture. In addition to these, a country is often affected by a

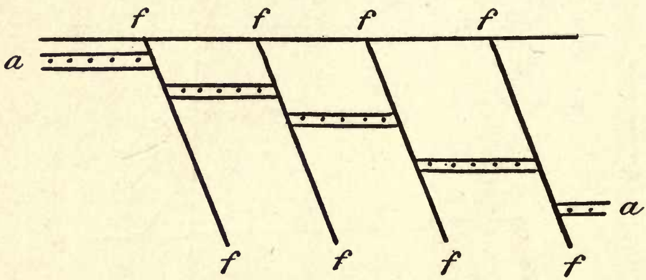


FIG. 69.

SECTION SHOWING STEP-FAULTS.

a a=A single bed thrown down successively to the east.

number of irregular faults, corresponding with the irregular joints which traverse strata. The trend of some of these is shown on the plan in Fig. 68, at *e*, *e*.

In any area the main parallel fissures often hade in the same direction, and at the same angle, the downthrow being to the same side in all the fissures. A system of faults of this nature is spoken of as a system of step-faults. A section through such step-faults, which in the figure are normal, is seen in Fig. 69. A system of reversed step-faults may also occur.

The fault-system figured in section in Fig. 70 is spoken of as a trough-fault system. In this case the bed *a* is thrown down to the east by one fault *b b*, and to the west by another *c c*. A trough-fault system might be produced by two contemporaneous faults,

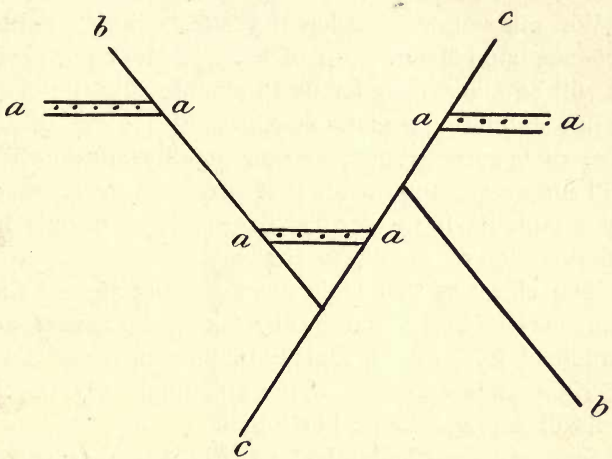


FIG. 70.

SECTION ACROSS BED AFFECTED BY TROUGH-FAULTING.

a a=A single bed displaced by fault *b b*.
The bed and the fault-fissure *bb* have been subsequently displaced by a later fault *cc*.

though in that case the portion let down would necessarily be compressed, and a considerable quantity of fault-breccia would be likely to occur in the fissures. In the case represented the system is due to faulting at two different periods, and it will be observed that the later fault *cc* has not only displaced the bed, but also the fissure of the earlier fault *b b*.

In many cases, the hades of faults vary both in direction and inclination in a comparatively small area. This is illustrated in Fig. 71, which represents a portion of a section figured in De la Beche's *Sections and Views Illustrative of Geological Phenomena.*

We must now consider the effects which faults produce upon the outcrop of beds as shown in plan. It will be convenient for us to assume that the plan is one exhibiting a plane surface, and not one of an area of uneven ground, and to avoid confusion we will suppose at the outset that the beds are affected by a fault having a vertical fissure, which trends in the direction of the dip of the beds.

The effect of this fault upon the outcrop of the beds may be best illustrated by taking the case of an anticlinal fold, with a fault extending in a direction at right angles to that of the anticlinal axis, which we will suppose to be horizontal.

Suppose a particular bed *a a* (Fig. 72) to crop out on either side of the anticlinal axis owing to its upper surface having been removed by denudation, and let the outcrops run in an east and west direction. Suppose that the bed is then displaced by a fault whose fissure runs north and south, and that the upthrow side is on the east. Then imagine that the upthrow side is denuded, so that the surface is once more reduced to a plane surface. A considerable amount of the bed *aa* will now have been denuded, and the two outcrops of the bed on the upthrow side will be further apart than they were before faulting occurred. The outcrops of the bed will now appear as in Fig 72.

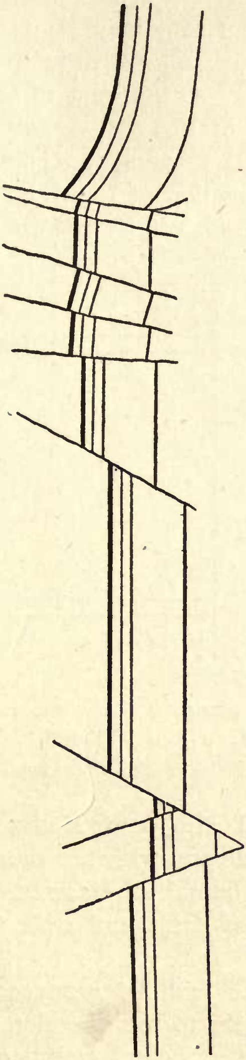


FIG. 71.

SECTION IN JARROW COLLIERY SHOWING FAULTS.

Approximately horizontal lines are coal-seams.
Highly inclined lines are faults.

(From De la Beche's *Sections and Views Illustrative of Geological Phenomena.*)

Any inclined set of strata may be regarded as forming one limb of such an anticline, and will be affected in the same way as the beds of one side of the anticline exhibited in Fig. 72. In other words, as the result of vertical movement along a line of fault which is in the direction of the dip, *the outcrop of the strata will be displaced laterally, as seen on a plane surface.*

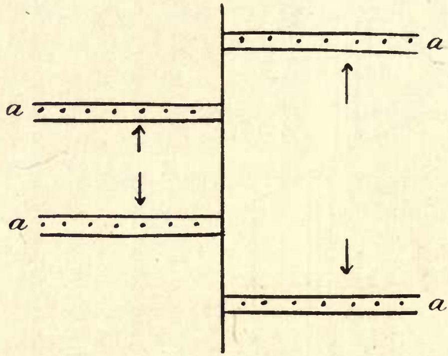


FIG. 72.

PLAN OF FAULTED AND DENUDED ANTICLINE, SHOWING OUTCROPS OF A SINGLE BED, *a a.*

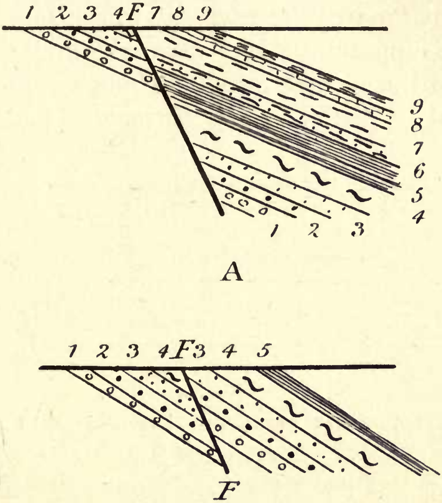
The downthrow is on the left side of the figure.

Such lateral shift will also occur if the fissure be inclined and not vertical, and with the same amount of vertical throw the lateral displacement will be similar with an inclined fault and with a vertical fault.

Again, a similar effect will be produced by any fault which runs obliquely to the direction of strike.

It should be noted that actual lateral movement may occur along a fault-fissure which would complicate the nature of the outcrop. The occurrence of such lateral movement is difficult to detect except in certain cases, and need not be discussed here.

The effect of strike-faults upon the beds must



B

FIG. 73.

SECTIONS OF STRIKE-FAULTS.

FF=Fissures of faults.

now be considered. In Fig. 73 (A) a series of beds 1 . . . 9 are represented as seen in a vertical section. They are affected by a normal strike-fault, and it will be seen that the beds 5 and 6 do not appear at the surface, but abut against the fault-fissure, so that anyone walking across the beds on the surface might suppose that the bed 7 immediately succeeded 4. Owing to the concealment of beds by strike-faults, these faults are often difficult to detect, though by following the fault until it dies out the concealed beds will appear at the surface. This is shown in plan in Fig. 74, where the fault is represented as dying out towards the east. It will at once be seen that the appearance is somewhat similar to that produced by unconformity, and much care must be exercised in distinguishing between a fault of this

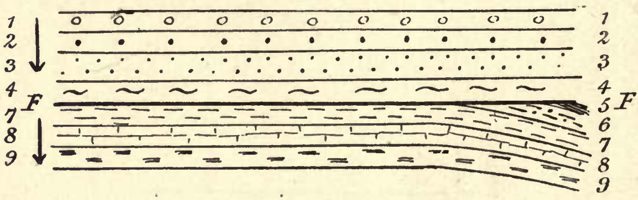


FIG. 74.

PLAN OF STRIKE-FAULT REPRESENTED IN SECTION IN FIG. 73 (A).

FF = Fissure of fault.

nature and an unconformity. The nature of the outcrop of a plane of unconformity has already been considered, and it has been shown that as that plane is not likely to be highly inclined from the horizontal, the outcrop will probably be sinuous on uneven ground, and the sinuosities will be sub-parallel to those of the outcrops of the beds of the newer set of strata; the fault-fissure, if approaching the vertical, will crop out in a line approaching a straight line, unless the fault itself be curved; in any case, it is not likely to be marked by many sinuosities. When the fault-fissure approaches the horizontal its outcrop will be, however, similar to that of the plane of unconformity, and the utmost care is requisite to distinguish a fault of this nature from a junction of unconformable beds, if the fault be strictly a strike-fault. If it be not so, the beds on either side will abut against the fault-plane, and difficulty is not then likely to arise.

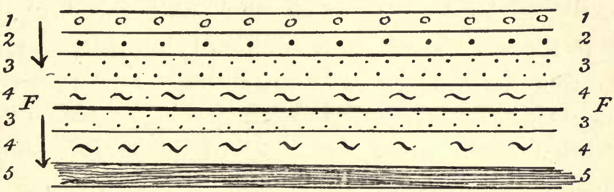


FIG. 75.

PLAN OF STRIKE-FAULT REPRESENTED IN SECTION IN FIG. 73 (B).

FF=Fissure of fault.

Should the strike-fault be a reversed fault, the strata, instead of being concealed at the surface, will be repeated, as shown in section in Fig. 73 (B). It is clear that the strata 3 and 4 will crop out twice upon the surface, as shown in the plan, Fig. 75. In this case no difficulty will be experienced in the detection of the fault if the reduplication of the strata be ascertained.

CHAPTER XV

GEOLOGICAL MAPS AND SECTIONS—*continued*

MODES OF OCCURRENCE OF IGNEOUS ROCKS

IF the reader will turn to Fig. 1, he will observe that the igneous rocks are either poured out on the surface to form volcanoes and volcanic plateaux, or are forced among the rocks of the earth's crust beneath the surface. If a molten rock be consolidated at the surface it is termed a *contemporaneous igneous* rock, being of the same general age as the rocks with which it is associated, *i.e.* newer than the rock upon which it rests and older than those which repose upon it. Should it be forced among the rocks beneath the crust, the age of its consolidation is posterior to the ages of the rocks into which it has been forced. An igneous rock which has thus been forced among other strata is termed an *intrusive igneous rock.* Lastly, there are rocks which may have consolidated in the place in which they became molten. These rocks would probably occupy extensive regions of the earth's interior, and would in most cases be of considerable thickness. Their character is yet little understood, and we need not devote further attention to them.

The contemporaneous rocks flow from the point or line of emission over the surface of the earth, and the lower surface is therefore parallel to the pre-existing earth-surface. If the rock does not flow any great distance, the upper surface may be convex, and of no great lateral extent. In ordinary cases, however, these lavas flow for a distance which is usually a considerable multiple of the vertical thickness; the former may be measured by scores of feet and the latter by miles. Accordingly, most lava-flows possess upper and lower surfaces which are approximately parallel to one another. They are usually also approximately parallel to the layers of volcanic ash with which they are associated. In this respect they differ from all intrusive rocks save the intrusive sheets or sills to be described below (p. 185).

Intrusive rocks force their way along planes of weakness existing in the rocks through which they break. When the planes are vertical or nearly so, as joint-planes, the intrusive rock forms a wall-like mass with sub-parallel sides. Such a mass is known as a *dyke.* These dykes crop out on the surface as strips of rock of varying width, depending mainly upon that of the dyke itself. The strips usually run across the outcrop of planes of bedding; though not necessarily so, as they may be forced along strike-faults, when they cannot be distinguished from sills on a flat surface, though on an uneven surface they may be distinguished from sills by their mode of outcrop, for being vertical or nearly so they will not cross the valleys and ridges with V-shaped outcrops having acute angles. The dykes as they appear at the surface vary greatly in horizontal extent. Many are only traceable for a few yards, while others run for scores of miles. Their course is often nearly straight, and accordingly when once detected they may often be readily followed—a matter of some practical importance, as the material which composes them is frequently valuable for road-metal, wall-building, and other purposes.

The rock composing the dyke probably resists weathering in a degree different from that of the rock through which it has been forced. If more easily weathered, its course is often marked by a depression upon the surface; if less easily, by a wall-like upstanding mass.

Dykes frequently radiate from the pipe of a volcano and traverse the lavas and ashes which have built up the volcanic cone. The actual pipe of the volcano is sometimes filled with once molten rock, at other times with fragments of volcanic rock of various degrees of coarseness, which have fallen into it. This filled-up pipe is known as a volcanic neck (see Fig. 39). The strata or volcanic ashes often dip towards it just beyond its circumference, and away from it at a greater distance. The filled-up neck will probably have a roughly circular or elliptical cross-section when viewed in plan on the earth's surface after the upper part has suffered denudation.

When the igneous rock is forced through minor irregular fissures, it forms string-like protrusions or thin, irregular dyke-like masses. These are known as *igneous veins*, and may often indicate the existence of a large mass of igneous rock in the immediate vicinity.

When igneous rocks are forced along horizontal or nearly horizontal planes, as planes of stratification, or faults with fissures approaching the horizontal, they may extend to varying distances along such planes. When the horizontal extent is very great as compared with the vertical thickness, the upper and lower surfaces of the mass are sub-parallel, and the mass is spoken of as an *intrusive sheet* or *sill.* If the vertical thickness be great as compared with the lateral extent, the upper and lower surfaces will not be parallel, and the mass is then spoken of as a *laccolite.* In many laccolites the lower surface often remains parallel to the direction of the surface along which the rock was forced, while the upper surface is frequently convex, and the rocks over it are arched up, as shown in Fig. 76 (sections).

It is obvious that the sill will appear at the surface in the same way as the beds with which it is associated. If beds and sills have been tilted and denuded, the strike of the sill will be parallel to that of the associated beds, and thus sills may be distinguished from dykes on uneven ground. The outcrop of the laccolite is more complicated, and two cases of outcrop of a simple laccolite are represented in Fig. 76, A and B. In A a section and plan of a simple horizontal laccolite are shown. The plan is supposed to be one showing the laccolite when denuded to a level marked by the upper level line, the parts above this line having been removed. The margin of the laccolite will appear on a horizontal surface as a circle, and the beds will crop out in circles concentric to this.

In B, a laccolite which has been inclined along with the associated beds is supposed to have been denuded to the level of the horizontal line. This laccolite will appear in plan as a plano-convex mass, and the strata will crop out parallel with the upper and lower surfaces of this mass.

It is evident that the difference between a sill and a laccolite is merely one of degree, and that as the horizontal extension of a laccolite is increased, its thickness remaining the same, it approximates more and more closely to the ideal sill.

In nature it is often a matter of considerable difficulty to distinguish a sill from a contemporaneous lava-flow. As it will probably not be necessary for the agricultural student to make this distinction, it need only be remarked that whereas a sill may metamorphose and send veins into the beds above it, a contemporaneous lava-flow cannot do so, as those beds were non-existent at the period of its consolidation.

The masses which may have consolidated far below the surface in the position in which they became molten may be of great extent and have very irregular boundaries. No vertical shaft sunk from the surface is likely to pierce through them. If a vertical shaft should pierce through intrusive rocks of great horizontal extent, these rocks will probably be of the nature of laccolites.

We have noted that dykes sometimes give rise to depressions owing to their being more easily weathered than the surrounding rocks. This weathering will probably be due to chemical solution of

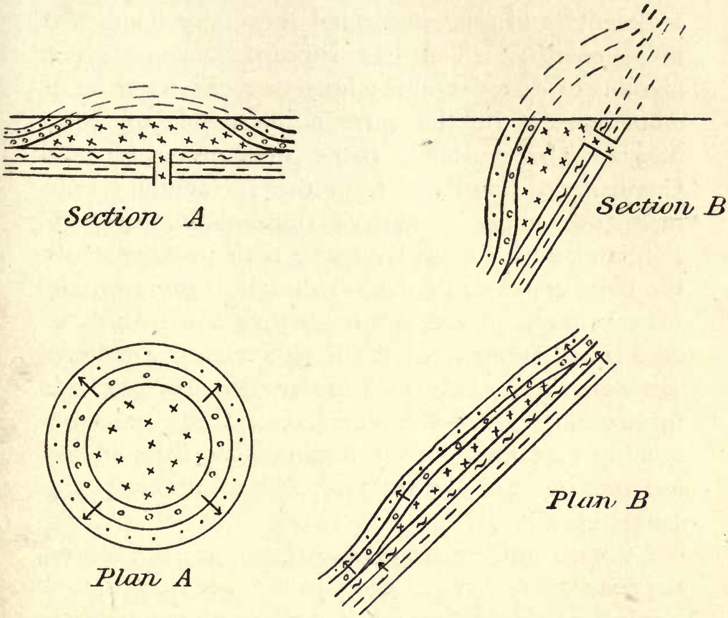


FIG. 76.

PLAN AND SECTIONS OF HORIZONTAL AND INCLINED LACCOLITES.

The broken lines in the plans represent rock which has been denuded.
The crosses indicate the igneous rock, and the other signs represent sediments.
The arrows show directions of dip.

Note.—By an error the igneous rock in plan *B* is drawn about half its proper width, which should be the same as that shown at the surface in section *B*.

some of the dyke-constituents. Agents of denudation as a whole affect igneous rocks less readily than sediments, and accordingly it is generally found that in a country which has suffered a considerable amount of denudation the igneous rocks stand up as eminences, while the surrounding rocks are worn away. The volcanic rocks of Snowdonia and Cumberland stand out from the surrounding sediments over miles of country. In Scotland, the Ochil, Pentland, and Sidlaw Hills owe their prominence to the large amount of igneous rock which they contain. Minor masses of igneous rocks give rise to isolated eminences, as many of the Scotch "laws," *e.g.* North Berwick Law. Laccolites are particularly prone to form eminences of this character. Lastly, sills frequently give rise to marked cliffs along their lines of outcrop, *e.g.* the Great Whin Sill of the North of England.

GEOLOGICAL SECTIONS.—A geological section represents the rocks as they would be viewed in a vertical cutting. Geological sections, therefore, show at a glance what might be discovered from careful study of a geological map upon which a very large number of observations were inserted.

For certain purposes it is desirable to ascertain the mode of occurrence of rocks for a considerable distance below the surface without entering into any consideration as to the nature of the rocks when traced laterally. This can be represented in the form of a column showing the rocks as they might be seen in a core formed by a gigantic boring apparatus. A section of this character is represented in Fig. 77, and is usually spoken of as a vertical section. The nature of strata traversed when boring mines is usefully represented by means of vertical sections.

When a section is drawn to represent the mode of occurrence of the rocks over a considerable extent of country, as indicated in Fig. 78, it is customary to speak of it as a horizontal section, though it is in reality a vertical one like the former; but as it represents the lie of the rocks over a considerable horizontal stretch of country, the term horizontal is generally applied. There is, of course, no real difference between the two kinds of section, and every gradation may be found from one kind to the other.

In drawing horizontal sections, it is usual to take a definite datum-line for the base of the section. The horizontal sections issued by the Geological

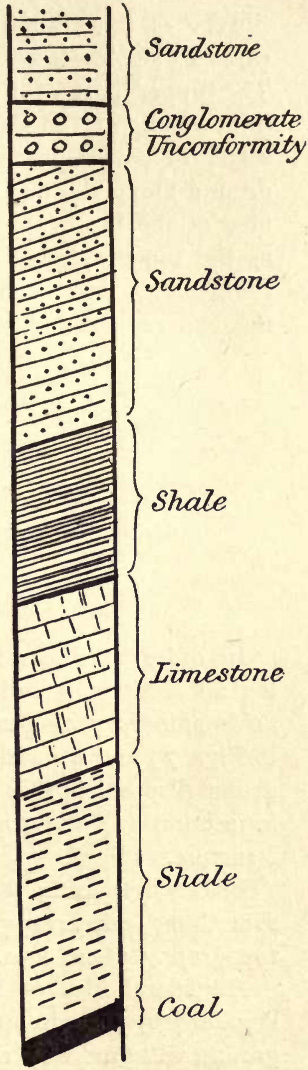


FIG. 77.
VERTICAL SECTION.

Survey of the United Kingdom are drawn in most cases to sea-level, which is taken as the datum-line. The upper part of the section is terminated by a line which, in the case of sections drawn to true scale, represents accurately the inequalities of the ground along the line of section. In this way some idea of the topography of the country is given, and as the topography is often largely dependent upon the geology, it is useful for many purposes to have the two represented.

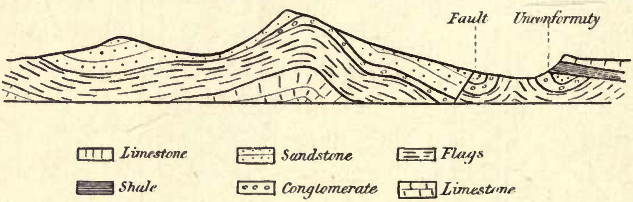


FIG. 78.

HORIZONTAL SECTION.

In order to illustrate the mode of drawing geological sections, it will be convenient for us to take an imaginary geological map, such as is represented in Figs. 79 and 80, and to discuss the data which are at our disposal in this map, to enable us to indicate in section (1) the topography, (2) the geological structure.

Before discussing this map, it will be well to say something concerning the manner in which the topography of an area is represented on a map.

A general idea of the topography of a country is gained by examining the trend of the rivers. The ground will gradually rise on either side of a stream,

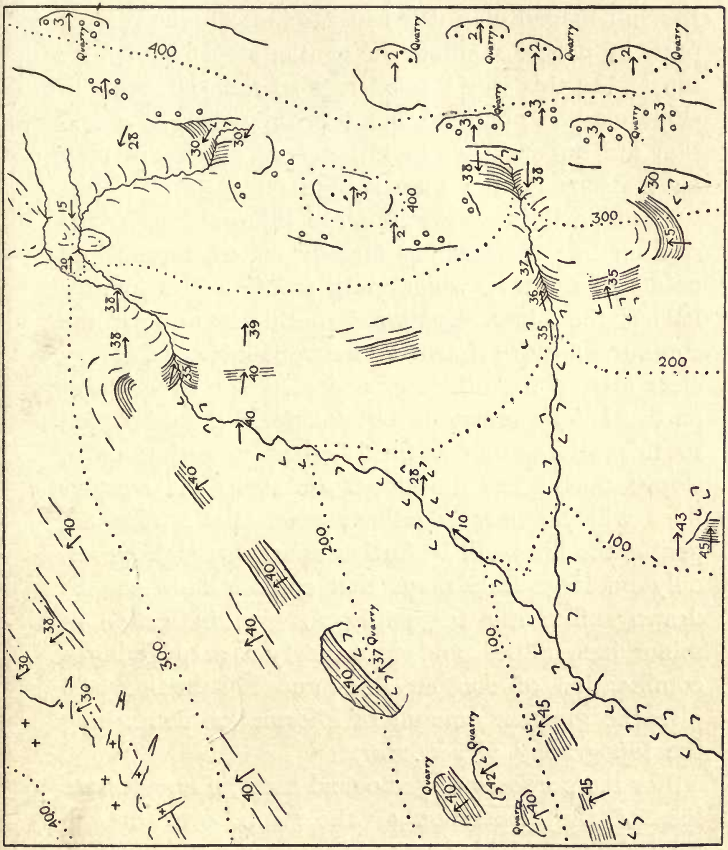


FIG. 79. MAP SHOWING ACTUAL ROCK-EXPOSURES.

until the culminating ridge is reached between two streams.

Further information is introduced by "hill-shading." In a hill-shaded map it is usual to indicate the steeper parts by darker shading, the gentler slopes by lighter tones. In this way a good idea of the variations in slope may be obtained, but the differences of elevation are not clearly brought out, as a low hill may have steeper slopes than a high one.

Contour lines give still more information. Each contour line is drawn, as already stated, through all points of the map which mark points in the country having the same elevation. In this manner, if the contour lines are drawn at frequent intervals, a very clear idea of the differences of elevation of different parts of the country is obtainable, and in addition to this, information is furnished as to variations in slope; thus, when the slopes are steep, the contour lines will be near together; when the slopes are gentle, the lines will be further apart. It is, however, only on large-scale maps that contour lines can be drawn sufficiently frequently to give indication of minor inequalities, and accordingly a map giving a combination of contour lines and hill-shading will give the greatest amount of information concerning the topography of a country.

For the purposes of geological maps, if an accurate idea of the disposition of the strata over uneven ground is required, contoured maps are very useful, and will save much work on the part of the geological observer in obtaining elevations.

We may now proceed to consider the construction

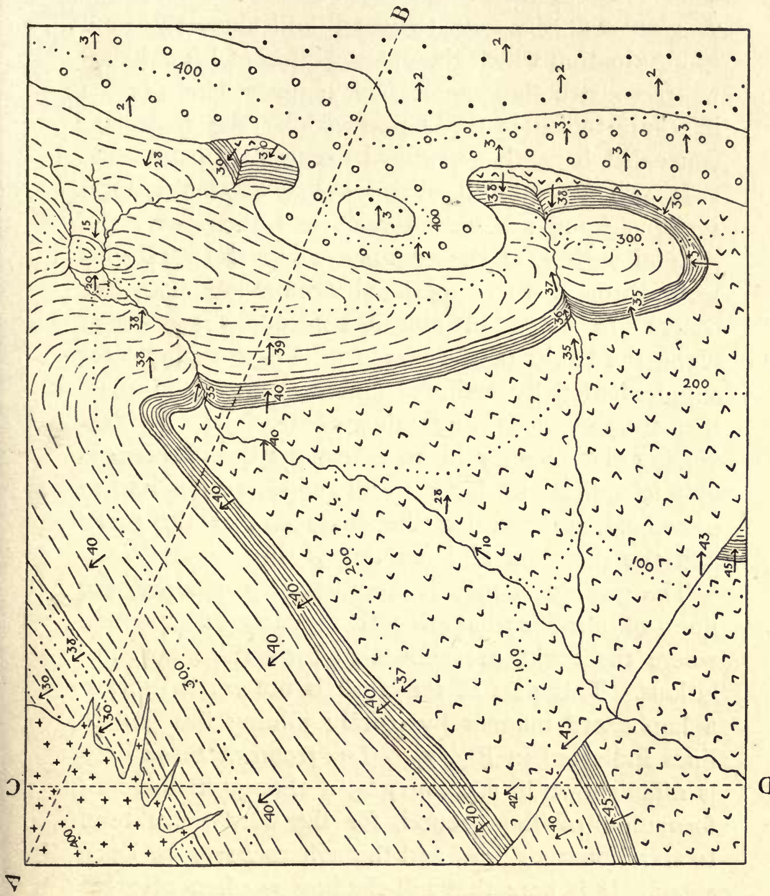


Fig. 80. Map restored from data given in Fig. 79.

of a geological map showing the distribution of the solid rocks beneath the superficial accumulations. A glance at the map (Fig. 79) will show the kind of information which the geologist has at his disposal when constructing geological maps. The portion left bare indicates those parts where the rocks are concealed beneath superficial accumulations.

It will be noticed at once that of the natural sections some are dotted here and there over the general surface of the country, where the rock projects through the superficial accumulations, while others are found in almost continuous succession along the banks of the streams. These sections are supplemented by artificial exposures made in quarries, ditches, wells, and other excavations. By traversing the country in all directions the observer is able to indicate on his map all the exposures he has examined, representing the characters of the rocks and the direction and amount of dip.

The geological map is completed by restoring the lines of stratification over those parts of the map where the rocks are concealed by surface accumulations. This part of the work is not carried out in a haphazard manner by merely joining the broken lines indicated in Fig. 79. The trend of these lines is often shown in a country by a change in the conformation of the ground, for the hard rocks tend to stand out as ridges and the soft rocks to be worn away. It is here that hill-shading is often of great utility to the geologist. In the figure the bed marked by small circles occurs on higher ground than the beds to the west of it, on which it is lying unconformably, and accordingly the slopes of the ground will probably enable the observer to draw in the lines of demarcation between this bed and the underlying beds even where the junction is concealed.

The utilisation of surface features for the detection of changes in the underlying rock is of paramount importance; change in the characters of surface accumulations as well as in those of solid rocks may frequently be detected in this manner. Some observers are much more qualified than others to detect the effect of rocks on the surface features; but in any case constant study in the field increases the power of everyone to utilise these features, and the student is advised to lose no opportunity of making himself acquainted with the geology and topography of his own area. To do this he should be provided with the published maps of the Geological Survey which represent his district, studying the map which shows the superficial accumulations in addition to that representing the solid geology, and he should traverse the ground, maps in hand, being specially careful to examine, as far as possible, those parts of the area where lines of demarcation between one set of rocks or accumulations and another are laid down.

The map which is represented in its unfinished state in Fig. 79 is shown in the completed state in Fig. 80, and a brief account of the geology of the district represented on it may now be given.[1]

Two sets of unconformable strata are represented upon the map, the newer being to the east, for the edges of the older strata abut against the line of

[1] The N. of the map is on left of page.

unconformity, while the outcrops of the strata belonging to the newer set do not abut against that line, but have a trend sub-parallel to it.

The older strata were folded into an anticline and syncline, the axes of which run a little E. of N. and W. of S. These axes are not horizontal, but are dipping nearly northward. The tops of the folds were denuded before the deposition of the newer set of strata. The student will notice the V-shaped outcrops where the beds cross the streams.

The older beds are affected by a *normal* fault running a little N. of W. and S. of E. at the S.W. corner of the map. It is normal, for the downthrow is on the S. side, as proved by newer beds on the south abutting against older ones on the north of the fissure, as seen at the W. end of the fault, while the direction of slope of the fissure is indicated by the small V which points down the valley.

At the N.W. corner of the map a mass of igneous rock is represented as being intrusive in the older set of sediments, and as sending dyke-like prolongations into them. These sediments would probably be found to be metamorphosed for some distance from the junction, and if it did not introduce too great complication, this belt of metamorphic rock might be represented, say, by a belt of darker shading.

There is no evidence as to the relative ages of the intrusion of the granite, the formation of the fault, and the deposition of the newer set of strata. All these events occurred after the deposition of the older set of strata, and that is all we can say from study of the map. If the fault further to the S.E. of its course, as represented, were found to pass under the bed represented by circles without displacing it, that would prove that the faulting took place before the newer set of strata was formed; if, on the contrary, it displaced them, it would indicate that the faulting was later than their deposition. Again, if a dyke from the granite were found cutting these newer strata, the intrusion of the granite would be posterior to the deposition of the strata. If the dyke ended off against the unconformable junction, it would almost though not quite certainly show that the intrusion was later than the deposition of the newer sediments.

Should the granite and its dykes not be seen near the junction, the discovery of pebbles in the lowest bed of the newer set of strata would prove that the granite was anterior to its deposition, and, indeed, it may be here remarked that examination of pebbles in conglomerates often furnishes important information to the geologist.

Lastly, it will be noticed that if the projecting part of the newer strata were detached from the main outcrop by further denudation at the heads of the tributary streams on either side of the neck which now joins the projecting portion to the main mass, an outlier would be formed.

SECTIONS.—In order to draw sections the student should first draw his base-line representing sea-level, or some other convenient level, and then draw his upper line, showing the variations in the height of the ground along the line of section. He should then insert the upper parts of the beds as observed along the line of section, or, when there is no exposure along that line, as near thereto as may be, as shown in Fig. 81. He will then be able to fill in the section as represented in Fig. 82, though it is clear that as this is largely inferential it may vary in some particulars from the actual trend of the rocks underground.

It is very desirable that the student should get some idea of sections drawn to true scale, the vertical being the same as the horizontal scale. If possible, he should study some of the geological sections drawn to true scale which are issued by the Government Geological Survey, examining the geological maps drawn upon the same scale in connection with his study of the sections; and if he can traverse the actual country of which the geology is represented in map and section, so much the better.

In many cases it is necessary to draw exaggerated sections, the scale of vertical heights being greater than that of horizontal distances. When this is done it is advisable to make the vertical scale some simple multiple of the horizontal scale. It must be remembered that should the vertical heights be exaggerated the dip of the strata must also be exaggerated in proper proportion. This is done in the sections (Figs. 82 and 83), which represent the geology of the map (Fig. 80) as exhibited along the lines A B and C D respectively.

The student should also remember that when a section is drawn obliquely to the dip of the strata the inclination of the beds as seen along that line

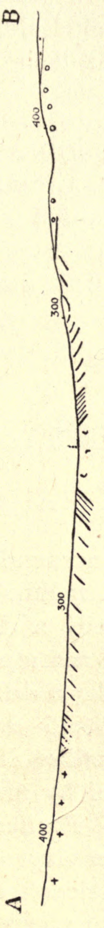


FIG. 81.

SECTION ALONG THE LINE A B IN FIG. 80.

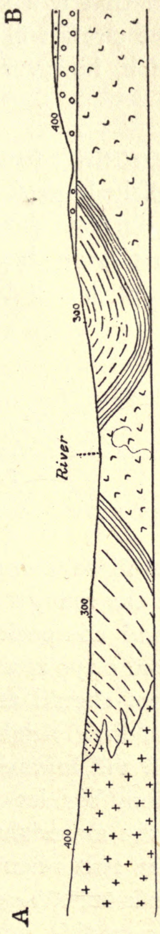


FIG. 82.

COMPLETED SECTION ALONG THE LINE A B IN FIG. 80.

of section will be at a lower angle than that of the true dip, and that if a section be drawn parallel to the strike, the strata will appear horizontal along the line of section, however great may be their actual inclination.

Maps showing Superficial Accumulations. —The published *drift-maps* of the Government Geological Survey show the distribution of the accumulations lying between the surface soil and the solid rocks, but it is impossible, with materials

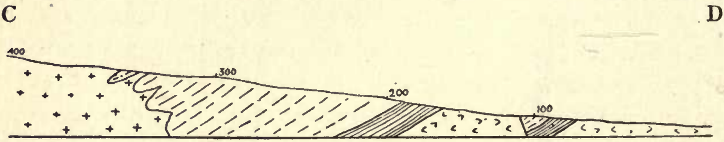


Fig. 83.

COMPLETED SECTION ALONG THE LINE C D IN FIG. 80.

so varied as those composing these accumulations, to represent the many variations in their lithological characters and composition, and usually a division into sands and clays is all that can be accomplished. Every student should attempt to make a drift-map of his immediate neighbourhood, should drift be present. He will insensibly learn to utilise all sorts of observations besides those obtained by mere inspection of the materials of the drift. For instance, he will notice that when sand rests on clay water is likely to break out along the line of junction, and he can often trace this junction by means of springs when it is concealed beneath the surface soil. A change in the character of the vegetation may also give important evidence as to the nature of the underlying accumulations. It need hardly be stated that such tests are also applicable when mapping the solid rocks. The thickness of the drifts being very variable, no study of maps is likely to give any information upon this head. The student must gather all the available information concerning his own district, remembering that, as these drifts often bury pre-existing inequalities beneath a fairly regular surface, great and sudden variations in the thickness of these accumulations may be expected. This is a point of great importance when seeking for water. Beneath the alluvial flats of several of our river valleys old buried valleys filled with drift may occur, and should this drift be impervious to water, an expected supply may not be obtainable. The ancient drift-filled valleys also depart in many cases from the present river-courses, and these buried valleys may be met with where no stream now occupies the surface.

As the superficial accumulations have rarely undergone any extensive earth-movement since their formation, it is unlikely that they will be found cropping out in parallel strips like the strata beneath. The character of their outcrop depends upon their origin. Boulder-clays and many glacial sands and gravels extend in sheets, often occupying considerable areas, though certain accumulations of glacial gravels known as kames and eskers may form linear ridges of greater or less extent, while moraine deposits frequently form mounds.

Raised beaches occur as terraces running more or less parallel to the coast, and at various heights above it, some of those of Scotland being one hundred feet above present sea-level.

Plateau gravels are often found in sheets and patches on the high ground between adjacent rivers, while ancient river gravels form terraces along the sides of valleys, with courses sub-parallel to those of the streams occupying the valley bottom.

The position of alluvia has already been described. They may be fluviatile, lacustrine, or estuarine, and their presence is usually readily detected owing to the flatness of the ground occupied by them.

In addition to drift-maps, attempts have been made to form soil-maps for various parts of the country, but more is required in this direction. The general variations in the soils of different parts of our islands will be considered when the rocks are described in order of their age.

NUMERICAL ESTIMATES.—The thickness of strata, the depth at which certain strata are likely to be found, the probable direction of outcrop of concealed strata upon the surface, and other numerical estimates are often of very great importance. A brief account will be here given of some of the most important considerations with respect to these.

In making estimates, if the angle of dip be taken, calculations frequently require the application of trigonometry, which can be obviated by stating the inclination of beds in *gradients* instead of in angles of dip. An inclined bed falls so many feet or yards vertically for a certain number of yards traced horizontally; thus, if *a* (Fig. 84) represents the point of outcrop of a bed *a c* at the surface, and *a c* represents the section of the bed parallel to its direction of dip, if a horizontal line *a b* be drawn, and a vertical line *b c* be drawn anywhere from it to cut the bed, then *a b* = *b c*, for as the angle of dip is 45° and the angle *a b c* is a right angle, the angle *b c a* must also be 45°, and the

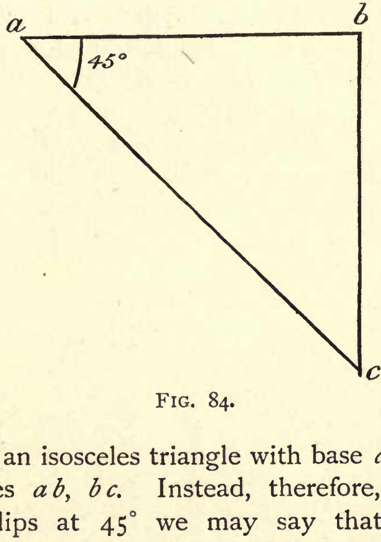


FIG. 84.

triangle is an isosceles triangle with base *a c* and two equal sides *a b*, *b c*. Instead, therefore, of saying that *a c* dips at 45° we may say that it has a gradient of 1 in 1, or that it falls 1 in 1, meaning that it falls one foot, or yard, or mile from the horizontal surface for every foot, yard, or mile measured along that horizontal surface. If the angle of dip be less, the gradient will also be less; thus with a dip of about 19° it is 1 in 3. If the dip be over 45°, the vertical distance will, of course, be greater than the horizontal; thus a dip of about 71° represents a gradient of 3 in 1. The exact amount can, of course, be found by protraction, the bed being indicated as shown in Fig. 84, with the angle of dip exactly measured; and if the right-angled triangle be then accurately constructed, the gradient is found by measuring the two sides of the triangle.

The following table, modified from one drawn up by the late Professor Jukes and published in the Geological Survey Memoir on the geology of the South Staffordshire coalfield, gives the gradients expressed as inches vertical to yards horizontal for a number of degrees up to 45°. Above 45° the gradient will be the reverse of that of the complementary angle; thus the gradient corresponding to 14° is 1 in 4 (approximately), that of 90° – 14° = 76° is 4 in 1 (approximately).

GRADIENT. Inches in a Yard.	Nearest Degree.	GRADIENT. Inches in a Yard.	Nearest Degree.
1	1½°	19	28°
2	3°	20	29°
3	5°	21	30°
4	6°	22	32°
5	8°	23	33°
6	10°	24	34°
7	11°	25	35°
8	12°	26	36°
9	14°	27	37°
10	16°	28	38°
11	17°	29	39°
12	19°	30	40°
13	20°	31	40½°
14	21°	32	41°
15	23°	33	42°
16	24°	34	43°
17	25°	35	44°
18	26°	36	45°

It need scarcely be remarked that should the level of the ground change between the point at which the bed comes to the surface and that at which its depth beneath the surface is required, the difference of level must be added to or subtracted from the depth given in the table.

If the width of outcrop of a stratum or strata be known, and also the angle of dip or the equivalent gradient, the thickness of that stratum or of the group of strata can be calculated or obtained by protraction. In Fig. 85 let *a c* and *b d* be the lower

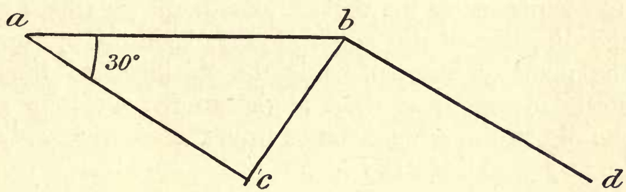


FIG. 85.

and upper surfaces of a bed which dips at 30°. From *b* draw *b c* perpendicular to *a c*, then *b c* represents the thickness of the bed; for as *a b* : actual width of outcrop :: *b c* : actual thickness of bed. Again, we can calculate the thickness of a bed or group of beds by knowing the amount of dip and the depth at which the bed or beds occur beneath a point whose distance from the outcrop of the beds has been measured (of course, making allowances for inequalities of the ground); and *vice versâ*, if we know the thickness and the amount of dip, we can calculate the depth at which the bed will be found beneath any point without measuring the horizontal distance from the outcrop. Thus, let *b d* in Fig. 86 represent the depth of the bed *a c d* below the point *b*. Then, as *b d* : *b c* :: actual depth : actual thickness. The following table, from the Memoir by Professor Jukes to which reference has been made, is a depth and thickness table giving the depth below the surface, and also the thickness (*i.e.* the thickness the strata would possess if they were horizontal) of strata at various inclinations. The ground is supposed to be horizontal, and the horizontal distance = 100; thus, with a dip of 45° the depth of the strata would be 100 yards below the surface at a point measured in the direction of dip and 100 yards horizontally from the point of outcrop, while the thickness of those strata measured at right angles to the direction of the dip, at the same distance from the outcrop, would be 70·7 yards, or 212·1 feet.

HORIZONTAL DISTANCE = 100.

Angle of dip.	Depth.	Thickness.	Angle of dip.	Depth.	Thickness.
1°	1·7	1·7	18°	31·8	30·9
2°	3·5	3·5	19°	34·5	32·6
3°	5·3	5·3	20°	36·6	34·2
4°	7	7	25°	46·9	42·3
5°	8·7	8·7	30°	58	50
6°	10·6	10·5	35°	70·5	57·4
7°	12·3	12·2	40°	84·2	65·6
8°	14·1	13·9	45°	100	70·7
9°	16	15·6	50°	119·0	76·6
10°	17·7	17·4	55°	143·0	81·9
11°	19·5	19·1	60°	174	86·6
12°	21·4	20·8	65°	214	90·6
13°	23·2	22·5	70°	275	94
14°	25·2	24·2	75°	368	97
15°	26.9	25·9	80°	575	98
16°	28·7	27·6	85°	1143	99
17°	30·7	29·2			

By means of the table of depth we can calculate the amount of downthrow of a fault if we know the dip of the beds and the horizontal distance between

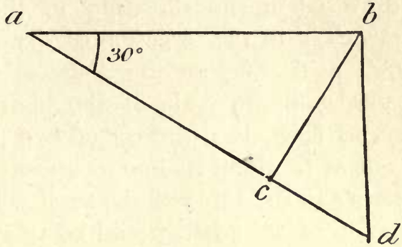


FIG 86

the outcrops of a particular bed where they abut against the fault-fissure on the upthrow and downthrow sides of the fault; or, conversely, knowing

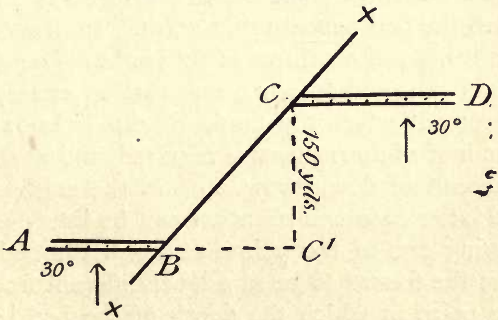


FIG. 87.
× × = Fissure of fault.[1]

the amount of downthrow and the dip of the beds, we can find the horizontal distance of the apparent lateral shift at the surface.

Thus, in Fig. 87, let a bed *A B C D* crop out

[1] The arrows should point *south*.

upon a horizontal surface along *A B* on the upthrow side of the fault with a fissure running in the direction × × and along *C D* on the downthrow side. From *C* draw *C′* in the direction of the dip, and from *B* draw *B C′* in the direction of the dip, cutting the line *C C′* at *C′*, and let the distance *C C′* represent 150 yards on the scale of the plan. Then, if there were no fault, the portion of bed *A B* would also crop out at *C′* along its line of strike.

On referring to the table of depth, it will be found that with a dip of 30° a bed would be 58 yards below the horizontal surface at a distance of 100 yards from its outcrop. Consequently, at a distance of 150 yards from this point it would be $58 + \frac{58}{2} = 29$, or 87 yards below the surface. That would be the depth to which a vertical shaft must be sunk at *C′* in order to reach the bed beneath that point. In other words, the fault has a downthrow of 87 yards. The student will find it useful to work out various examples of displacement when the angle of dip is known and the amount of downthrow is required, and also, given the amount of downthrow, to find the angle of dip. In the latter case complication can be introduced by supposing one of the points at which the bed abuts against the fissure to be at a level different from that of the point at which the depth of the bed beneath the surface is known.

It is often important, from observations of the amounts and directions of apparent dips, to find the true dips. This can be done by protraction if the dips be expressed in gradients, or if given in degrees the corresponding gradient can be found by reference to the table on p. 204.

Suppose that we discover in a cutting which runs in a W.N.W. and E.S.E. direction that the apparent dip of a bed along that line is 1 in 12 towards E.S.E., and that in another cutting trending S.W. and N.E. the apparent dip of the same bed is 1 in 8 towards the S.W.; then from a point *A* (Fig. 88) draw two lines *A B′* and *A C′*, the former in an E.S.E. direction and the latter in a S.W. direction. Along the line *A B′* mark off twelve inches, or half-inches, or any

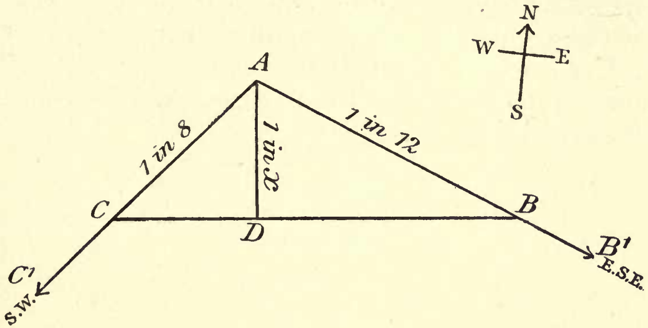


FIG. 88.

convenient length, and eight inches, or eight times the unit of measurement adopted, along the line *A C′*. Let the line *A B* represent the length of twelve of these units along *A B′*, and *A C* eight of them along *A C′*. Join the points *B C* by a straight line. From *A* draw *A D* at right angles to *B C;* then the direction *A D* will represent the direction of the true dip, and the amount of true dip will be obtained by finding the number of units of measurement along the line *A D.* The amount of apparent dip in any other direction can be obtained by drawing a line from *A* along the required direction, so as to cut *B C* or *B C* produced. The measurement of the distance from *A* to the point where *B C* or *B C* produced is cut gives the amount of apparent dip in that direction.

It is sometimes desirable to calculate the deviation of the outcrop of a bed from its direction of strike when it crops out upon uneven ground. This can readily be done on a well-contoured map, if the inclination of the bed be expressed as a gradient. As such a requirement will not often arise in the case of those occupied with agricultural pursuits, it will suffice here to state that the student will find the method fully explained in Professor A. H. Green's *Physical Geology* (chap. xi.).

Section IV

STUDY OF THE STRATA OF THE BRITISH ISLES IN THE ORDER IN WHICH THEY WERE FORMED

CHAPTER XVI

PRELIMINARY REMARKS UPON THE STRATA

THE relative ages of the strata of any area are discovered by finding out the order of superposition of those strata, and by examining the included relics of former organisms. Other tests are also occasionally applicable, as, for example, the detection of fragments of earlier strata included as pebbles in later deposits, and, in the case of superficial accumulations, the relationship between these and the surface topography may be important, as in detecting the relative ages of river-gravels in an area.

For most purposes, however, the tests of superposition and that of included organisms are most important, and we may proceed to state the two great stratigraphical laws which govern the application of these tests.

I. Of two strata, that which was originally the lower one is the older.

II. The age of strata may be ascertained by study of their included organisms.

The former of these laws requires little comment. As strata have been laid down in sheets on more or less horizontal surfaces, it is clear that the overlying sheets are more modern than those upon which they repose.

In most areas this order is retained even after the beds have undergone a considerable amount of disturbance; in fact, the test of superposition is applicable until the strata become reversed, when older strata overlie newer beds. As reversal of strata is comparatively rare, the test of superposition is applicable over very wide areas, and the establishment of the order of succession of strata in any region is usually accomplished as the result of application of this test.

The truth of the second law has been ascertained as the result of accumulated observations.

The general applicability of the former law having been ascertained, it was noticed that strata occupying different positions in the vertical succession of strata in any area contained different remains of included organisms, or *fossils* as they are termed, whereas strata in the same general position in that vertical succession, and therefore of the same age, were apt to contain similar fossils, and accordingly Dr. William Smith, to whom the original classification of our British strata is due, was enabled to establish the law that strata were within certain limits identifiable by their included organisms, and subsequent researches have tended not only to confirm Smith's discovery, but to prove that the test of included organisms can be applied to even smaller groups of strata than Smith imagined.

It is desirable that the student should possess some acquaintance with the characteristic fossils of the more important geological divisions. No attempt will be made in this work to give illustrations of a large suite of fossils characteristic of the various formations, for knowledge of fossils derived from inspection of rough figures, without knowing anything of the distinctive characters of the fossils, is unscientific and often misleading. The appreciation of these characters is only possible when the student possesses some knowledge of the structure of the hard parts of the various groups of organisms derived from inspection of actual specimens. Accordingly when the strata are treated in the order of their succession, brief descriptions and figures of some of the more important of the different groups of fossils will alone be given. These should in all cases be studied with the aid of actual specimens, and it will be assumed that the student has access to a museum. At the end of the description of each principal division of the strata an enumeration of some fossils characteristic of that division will be made, and the student should examine actual specimens of these also, and consult his teacher, or some descriptions of the fossils, to ascertain what are the characteristic features of each organism. If this cannot be done, it is better to omit the study of the fossils, which in most cases have very little direct bearing upon matters which are connected with agriculture.

When the order of succession of the beds of any region has been determined, it is requisite that these beds should be classified. Classifications are naturally based upon some community of character of a group of beds of the same geological age, or on the existence of sharp lines of demarcation between such a group and those of preceding and succeeding ages. The particular characters which are taken into account in founding a classification may vary; thus a classification might be founded upon similarity of lithological characters among the beds of a group of strata, or on the similarity of the fossil contents of those beds, or, again, on a marked physical discordance which separates one group of strata from another. It often happens that change of lithological characters is accompanied by change of organic contents, and that those changes frequently occur at the horizon where a marked physical discordance also exists.

The classification of the British strata, which has undergone frequent modifications since it was first drawn up by William Smith, is largely based on lithological characters, but other circumstances have been taken into account.

Such a classification must necessarily be of local application, as the lithological characters of a group of strata of a particular period cannot remain unchanged over vast areas, but when once the time-divisions of one region are drawn up, the terms applied to these divisions may be used in areas where changes have occurred at times distant from those when they took place in the type-region, just as an English historian may speak of events in a foreign country as having happened in the Victorian era, though the inhabitant of that country would also have a chronological division of his own.

In geology, however, the classification originally based upon study of the British strata has, with modification, become of universal application, as may be seen by glancing at foreign works, where such terms as Devonian and Silurian are applied to rocks of distant regions, though the type-rocks to which the names were applied are found in Devonshire and in the Welsh borderland—the region of the old Silures.

In the case of a classification which has undergone and is still undergoing modification, there must be many differences in detail in the subdivision of the groups of strata, but the main divisions are fixed to the satisfaction of all geologists.

Strata are divided into *groups;* each group is further divided into *systems*, each system into *series*, and each series into *stages*. We speak of the Lower Gault stage of the Gault series of the Cretaceous system of the Secondary group. The groups as originally defined were *Primary*, *Secondary*, and *Tertiary*, also termed *Palæozoic*, *Mesozoic*, and *Cænozoic*. Modifications of this classification have become necessary, for below the Palæozoic rocks as originally defined is a great group still little understood, which we shall refer to simply as that of the Precambrian rocks, thereby indicating that their age is anterior to that of the strata of the lowest (Cambrian) system of Palæozoic times. Again, some writers have advocated the adoption of a division Quaternary, above the Tertiary. These Quaternary rocks are, however, usually included in the Tertiary, though from their great importance to the agriculturist the name may be utilised.

The lines of demarcation between the groups were drawn on the supposition that a great hiatus occurred between the organisms of one group and those of the group which succeeded it. Such a hiatus does not really exist; the supposition of its existence was due to imperfect knowledge, and the subdivision of the strata into groups is purely conventional, though in Britain the absence of strata of particular ages between the rocks of Primary and Secondary and Secondary and Tertiary groups respectively does give those divisions more than conventional significance as far as our own country is concerned.

The beds which are included in a system are usually thrown together, on account of the possession of assemblages of fossils which differ in a marked degree from those of the preceding and succeeding systems, though in some cases the division has been made mainly by reference to lithological characters, as in the case of the Triassic rocks. It is usually found, however, that the rocks of one system exhibit great variety of lithological character; thus the rocks of the Carboniferous and Cretaceous systems consist of limestones, sandstones, and muds, associated in the case of the former with coals.

The rocks which are placed together to form a series are more frequently of one particular type, though even here we often find variations of character. A stage is still more probably composed of rocks of uniform lithological character, and is often characterised by one special type-fossil.

The following table of classification of the British strata shows the names of the groups and systems which will be adopted in the descriptions of the strata, while the minor subdivisions into series and stages will be considered under the head of each system, as these are described seriatim.

Groups.		Systems.
Tertiary or Cænozoic	Quaternary	Recent.
		Pleistocene.
		Pliocene.
		(Miocene).[1]
		Eocene.
Secondary or Mesozoic		Cretaceous.
		Jurassic.
		Triassic
Primary or Palæozoic		Permian.
		Carboniferous.
		Devonian.
		Silurian.
		Ordovician.
		Cambrian.
Precambrian.		

It must not be supposed that each group is of equal importance to any of the others. The Primary group, for instance, is probably much more important, as regards lapse of time during the accumulation of the rocks which are included in it, than the Secondary and Tertiary groups combined, while the Secondary group in the same way is more important than the Tertiary.

The same remark may be made about the systems.

[1] Absent from Britain.

Indeed, the later divisions placed as systems assume so prominent a position on account of the recent date of their component rocks. The Pleistocene accumulations, for instance, might be grouped as a series, or even as a stage, if found among the Carboniferous rocks.

Again, it must not be assumed that the time during which the strata of two divisions were accumulated was of equal duration because the component strata of the divisions are of approximately equal thickness, for the strata of one division may have been accumulated very slowly in deep water and those of another rapidly in shallow water. Indeed, we find very great variations in the thickness of the strata when traced laterally; thus deposits which are many thousands of feet in thickness in Wales may be represented by sediments in the South of Scotland whose thickness is measured by hundreds of feet only.

The distribution of the various great groups of rocks over the British Isles will be seen on referring to the map forming the frontispiece. Leaving minor details out of account, it will be noticed that Britain may be roughly divided into four areas, each occupied mainly by one of the groups. That portion of Scotland which lies to the north-west of a line drawn from the Firth of Clyde to Stonehaven, south of Aberdeen, is largely occupied by Precambrian rocks, and it may be mentioned that this line is continued into the North of Ireland, owing to the occurrence of these rocks in Donegal.

The next line to be noticed is one which extends with somewhat sinuous course from the mouth of the

Tees to Start Point, in Devonshire. With few exceptions, the rocks occupying the area between this line and that noticed above are referable to the Primary group. These rocks occupy the Central Valley and Southern Uplands of Scotland, the Lake District of England, the Pennine Chain and moors on either side of it, Wales, Devon and Cornwall, and also the greater part of Ireland.

A third line is traceable from the coast of Norfolk to the neighbourhood of the Isle of Purbeck. The area between the second and third lines is chiefly occupied by Secondary rocks, which also stretch to the east of the third line in one tract, occupying the Kentish Weald and the North and South Downs, while the rest of the area lying to the south-east of the third line is chiefly covered by Tertiary rocks.

From an agricultural point of view the rocks of the earth's crust are important, not only on account of the materials which they furnish for the formation of soil, but also because of their effects in controlling the surface features of the land.

Other things being equal, the older the rocks the more durable they will in all likelihood be, for they have been subjected to the various mechanical and chemical processes tending to consolidate and harden them for longer periods of time than the newer rocks. We accordingly find that the crystalline Precambrian rocks of Scotland and slaty Primary rocks of Scotland, Cumbria, Cambria, Devon, and Cornwall are, as a rule, the most durable of the British rocks. Next to these are the limestones and gritstones which are dominant among the Upper Primary rocks of the

Pennines, the flanks of Cumbria and Wales, the Central Valley of Scotland, and the central portions of Ireland. Following these in durability are the Secondary rocks of England, and least durable of all are the Tertiary beds of the South and East of England.

It is natural, therefore, that the most elevated tracts should occur among the Precambrian and Primary rocks, and that is the case. The Highlands of Scotland are carved out of crystalline schists; the hills of Wales, the Lake District, and the Southern Uplands of Scotland are formed of Primary slates; the moors and limestone hills of the Pennines, the Mendips, and other smaller tracts are composed of Upper Primary gritstones and limestones; the undulating region of many parts of England consists of Secondary rocks, while the Tertiary rocks are found to occupy comparatively flat country.

These variations in height, which are thus seen to be largely due to variations in the characters of the constituent rocks of a region, produce important effects upon the rainfall, and are herein also of importance in affecting agriculture. Apart from the variations in rainfall due to geographical position, it is well known that the rainfall is greater in the hilly regions than in the flatter tracts, and accordingly the Highlands of Scotland, the elevated tracts of Ireland, the hills of Cumbria and of Wales have a greater annual rainfall than the lower country to the south and east.

The second of the three lines to which we have referred, which separates the Secondary rocks from those of Primary age, also roughly separates the upland from the lowland regions of the British Isles. To the west of this line we find hard rocks, elevated land, and abundant rainfall; to the east of it softer rocks, lower land, and a smaller rainfall. The country to the west of this line is accordingly characterised by its abundance of waste land and grazing ground, while the principal corn-growing areas of our islands are situated on the east side of the line.

The truth of these remarks will at once be apparent if the student will consult a physical atlas and compare the geological map of our islands with that showing the elevations and also that of the rainfall.

Before we proceed to describe in detail the characters of the rocks of the various systems, it will be well that the student should grasp the dominant features in the geological structure of our country.

Speaking broadly, the British Isles may be regarded as forming the south-eastern limb of a gigantic anticline, the axis of which runs off the west coast of Scotland and the north-west of Ireland, and accordingly in passing to the south-east of this axis we proceed generally from older to newer rocks.

Were the anticline a simple one, the beds would dip regularly away from its axis towards the south-east. In reality, however, it is complicated to a very high degree, the principal complexities being due to unconformities, minor folds, and faults. As the folds and faults were produced during those periods of earth-movement which gave rise to the unconformities, it will be convenient if we consider the unconformities at the outset.

Leaving minor changes out of account, the geological history of our island may be regarded as consisting of periods of continental conditions, alternating with marine conditions. Without discussing the origin of the little-understood Precambrian rocks, we will take these as forming the eroded platform on which the other rocks of Britain repose. At the end of Precambrian times our area was essentially continental, and denudation had worn down the old rocks to an undulating surface. Upon the depression of this surface beneath the sea, the early Primary sediments were laid down unconformably upon the denuded edges of the Precambrian rocks. Leaving out of account minor movements of uplift, the whole of early Primary times, when the Cambrian, Ordovician, and Silurian strata were deposited, may be regarded as forming one long marine period, during which the strata, as a whole, were laid down in parallel sheets over the Precambrian platform. At the end of Silurian times great earth-movements occurred, elevating the Lower Primary sediments to form land-masses, consisting of folded and altered rocks, which were bent around axes having a general north-east and south-west direction. During this continental period much denudation occurred, and accordingly over considerable tracts of Britain the Upper Primary strata rest with a marked discordance on those of Lower Primary date. To this period of great uplift, also, we owe the still prevalent north-easterly and south-westerly strike of our Lower Primary sediments, while the slaty structure of many of the Lower Primary sediments was impressed upon them as the result of the great lateral pressure to which they were subjected at this period. The Upper Primary sediments were deposited on the floor of ancient rocks which had been uplifted and largely denuded. This floor was uneven, and accordingly the lower members of the Upper Primary rocks, namely, those belonging to the Devonian period, were deposited locally, and are practically absent from the borders of N. Wales and Cumbria. As the result of denudation and deposition in the hollows, a comparatively level tract was formed at the end of Devonian times, and on this the Carboniferous sediments were formed during the following marine period. At the close of Carboniferous times another great uplift, or series of uplifts, commenced and continued through the times of accumulation of the Permian and Triassic rocks. As a result of these movements the Precarboniferous rocks must have been again affected, but as they already possessed high dips over many areas, as a consequence of the post-Silurian movements, their existing dips and strikes were only modified as a consequence of the post-Carboniferous movements.

It was quite otherwise with the Carboniferous rocks, which were practically horizontal after deposition. These rocks were thrown into a series of folds, giving rise to ridges and intermediate basins, for the post-Carboniferous folds occurred around axes having two principal directions—the one north and south, the other east and west. The former, which may be spoken of as the Pennine system of folds, was the dominant system in the North of England, while the latter, or Mendip system, predominated in the South of England and also in the South of Ireland.

These systems of folding are responsible for the existence of our coalfields in the form of basins flanking the ridges from which the coal-measures were denuded. We shall have occasion to speak at greater length of these folds and their effects in a subsequent chapter.

The principal movements at the date to which we are now referring had ceased before the deposition of the Permian and Triassic rocks in Britain, and accordingly the Permian rocks rest with a marked discordance upon the upturned and denuded edges of different members of the Carboniferous system, and these Permian rocks, though placed in the Primary group, form physically a base to the Secondary rocks of Britain.

The Secondary rocks were laid down on the Permian rocks through a long marine period, which extended with minor breaks into the middle of Tertiary times. There are, it is true, unconformities at various horizons, especially in the middle and at the summit of the Cretaceous rocks, but they do not affect the strike of the rocks so extensively as those unconformities which have been already noted, and accordingly the Secondary and early Tertiary rocks crop out in sub-parallel strips.

These outcrops are the result of the final great set of earth-movements which affected the strata of the British Isles—movements which occurred in middle Tertiary times, culminating in the Miocene period.

So far as Britain was concerned, these uplifts caused a tilting of the newer rocks in such a manner as to cause them to dip, usually at a low angle, in a

Comparative Sections, Showing the Relations of Geological Structure and Contour to Agriculture

(The Heights are Magnified Six Times.)

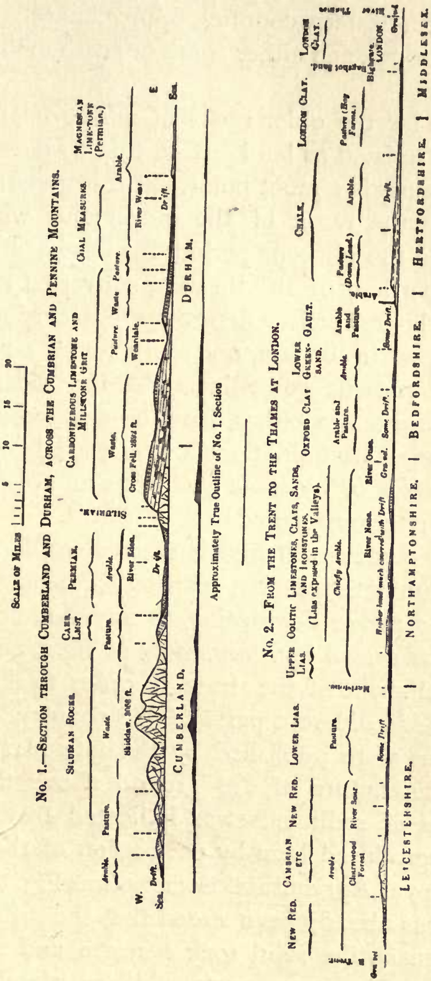


Fig. 89.

direction south of east, the dip being nearly east in the north-eastern counties, approximately south-east further south, and either south or north in the southern counties.

How far the older rocks of northern and western Britain existed as land before this final set of great movements is a moot point, but it is generally agreed that, as the result of the movements which culminated in the Miocene period, the east, south-east, and south portions of Britain were converted into land.

The later Tertiary deposits are accordingly poorly developed in Britain, and only found near portions of the present coast-line, and the older rocks of other areas are either bare or covered with those superficial accumulations of terrestrial origin which are spoken of by some geologists as appertaining to the Quaternary period.

The student will find it convenient, in addition to an examination of the map of England while reading the above description, to examine some typical sections drawn approximately at right angles to the general strike of the strata, in order to discover how they lie in different parts of the country. Two such sections were published by the late Mr. W. Topley, and the nature of the ground above the different groups of sediments was indicated thereon. They are reproduced here by permission of the Council of the Royal Agricultural Society (see Fig. 89).

It has already been stated that the drift accumulations mask the solid rock beneath, and are of great thickness in many parts of these islands. It must therefore be remembered that, when speaking of the influence of the rocks of different geological periods in affecting the composition of the soil, this influence may not be felt when the solid rocks are thickly covered with drift. For instance, in many parts of East Anglia the chalk, which is the solid rock nearest the surface, is so thickly covered with drift that the soil is not affected by the underlying chalk except in so far as it may have yielded some of its substance to the drift, rendering the latter calcareous, but the nature of the soil depends in a high degree upon the character of the drift.

CHAPTER XVII

THE PRECAMBRIAN AND LOWER PALÆOZOIC ROCKS

IT has already been stated that the great mass of British rocks of Precambrian age is found in Scotland, north of a line drawn from Stonehaven on the east coast to the Firth of Clyde on the west, and continued across the north-west of Ireland. The whole of this area is, however, not occupied by these rocks, for we find a strip of older Primary rocks running near the west coast from the neighbourhood of Cape Wrath to Skye. Newer Primary rocks are well developed around Moray Firth, and extend to the Orkney Islands. A small development of Secondary rocks is found in some of the western isles, and also in Sutherland; and lastly, great masses of igneous rock of various ages break through the Precambrian rocks of the mainland, and form a portion of some of the western isles, as Mull and Skye.

In addition to this great development of these very ancient rocks, we find representatives of the Precambrian period cropping out in smaller patches further south, owing to the existence of minor folds and faults, which have brought up portions of this ancient platform to a height sufficient to allow them to have been laid bare by the agents of denudation. Accordingly small tracts of rock, which have been referred to the Precambrian period, are found in Anglesey, Carnarvonshire (between Bangor and Carnarvon, and further to the south-east in a strip crossing Llanberis Lake), near St. Davids, and other parts of Pembrokeshire, and in England in the Malvern Hills, the Wrekin district, near Nuneaton, the Lickey Hills, Charnwood Forest, and possibly also in Cornwall.

The prevailing note of these British rocks is the predominance of crystalline schists, though the southern patches contain many igneous rocks which have not been converted into schist, and occasional sediments and volcanic ashes, while in Scotland there is a considerable development of sandstone—the Torridon sandstone—which there rests unconformably upon the schistose rocks.

The origin of the schistose structure has already been referred to. Many of the rocks are known to have been originally igneous, while others are undoubtedly sedimentary. Of a great proportion the original nature is unknown. There is no doubt, however, that as the result of metamorphic change crystallisation occurred in igneous and non-igneous rocks alike, and the present characters of the rocks depend largely upon the crystalline structure and the divisional planes of foliation which were developed in these rocks as the result of metamorphism.

Some writers have spoken of these ancient rocks as Azoic, from the supposed absence of life therein. This is a question into which we cannot now enter; suffice it to say that the traces of life which have been discovered in the British Precambrian rocks are very obscure.

We have already noted that, owing to the variations in the characters of crystalline schists, the soil derived therefrom may vary considerably. In our own country, where these rocks have often been swept clear of their weathered exterior by glacial action in Quaternary times, and the present rock-surfaces are unweathered and often smoothed, a very poor soil is derived from them, and accordingly the areas occupied by these Precambrian rocks are, as a whole, characterised by waste land. When the bare rock does not reach the surface, it is covered by extensive tracts of heather, or by bleak peat-mosses, and it is only here and there, among the Quaternary accumulations of the valley floors and sides, that cultivation can be carried out on a small scale.

THE PRIMARY OR PALÆOZOIC ROCKS

The Primary rocks of Britain are conveniently divisible into upper and lower sub-groups, each sub-group comprising three systems, thus:—

Permian	Upper	Palæozoic or Primary.
Carboniferous		
Devonian		
Silurian	Lower	
Ordovician		
Cambrian		

The Lower Primary rocks are chiefly characterised by the predominance of slates and the rarity and thinness of the limestones. The Upper Primary rocks, on the other hand, contain important limestones, and the slates of this group are chiefly confined to the South of England and of Ireland.

The distribution of these rocks in Britain has already been briefly indicated, and will be more fully described when we discuss the characters of the rocks of the respective systems. The Lower Primary rocks, owing largely to climatic causes, are marked by waste land and sheep pastures, the arable land being very limited. Much of the high ground occupied by the Upper Primary rocks is also waste land or pasture, though the proportion of arable land over these rocks is greater than in the case of the country of the Lower Primary strata.

Before describing the systems in order it will be well to offer a few remarks concerning the nomenclature applied to the Lower Primary rocks. The term "Silurian" is sometimes used in geological literature to include the whole of the Lower Primary rocks; at other times it refers to the upper two-thirds, which we have spoken of as Ordovician and Silurian (this is the case, for example, in the figure on p. 227 taken from Mr. Topley's paper); while in this work we use it only for the upper third of the sub-group. It is necessary to make this explanation, or the student of other geological treatises may be confused by the varied application of the term as used in different books.

THE CAMBRIAN SYSTEM

The rocks of this system are developed in Wales in parts of Carnarvonshire and Merionethshire and in Pembrokeshire. A few small patches are found in some of the western counties of England, and a strip of Cambrian rocks extends from the north coast of Sutherland in a general southerly direction to the island of Skye. The Welsh areas, and especially the regions around Llanberis and Harlech in North Wales, contain the most extensive British development of the rocks of this system. They have here a thickness of from ten to fifteen thousand feet, and are divided into the following series:—

Tremadoc Slates[1] . .	1,000 feet.
Lingula Flags . .	5,000 „
Menevian Beds . .	600 „
Harlech and Llanberis Beds over . . .	6,000 „ in places.

The prevailing rocks consist of greenish-grey grits interstratified with mudstones, which, owing to the subsequent impress of cleavage, usually occur as slates. From their great thickness the Lingula flags and the Harlech and Llanberis beds exercise the greatest influence upon the character of the ground. Each of these divisions consists of alternating grits and slates, which are usually durable, the grits resisting weather more than the slates. The ground occupied by

[1] Here, as elsewhere, in these accounts of the strata the rocks when tabulated in a columnar form are arranged with the highest strata at the top.

these Cambrian beds is therefore usually waste land. Corn is grown in places—mainly oats and barley. Many of the hills composed of Cambrian rocks, in addition to those occupied by the Ordovician and Silurian rocks, are well adapted for sheep-grazing.

The principal economic products of the rocks of the Cambrian system are slates. The principal supplies are furnished by the Llanberis beds of Llanberis, Nant Francon, and Nantlle, in Carnarvonshire; these are the well-known green and purple slates. Darker slates are furnished by the Lingula flags of Carnarvonshire and Merionethshire, and to some extent also by the Tremadoc slates. Many of the massive grits are useful for building-stones. Ores of copper, lead, and other metals are occasionally worked. In Scotland a band of limestone runs southward from Loch Eribol towards Skye.

Considering the obscure nature of the fossils of Precambrian rocks, the fauna of the Cambrian system is remarkably varied, for the principal groups of the invertebrates are represented. The most abundant fossils belong to the brachiopods (see p. 224) and the trilobites. The latter group may be regarded as the dominant one in Cambrian times. The trilobites are usually referred to the Crustacea, which include the crabs and lobsters of the present day, though some place them among the Arachnida, now represented by spiders and scorpions. The hard covering of the trilobite consists of three parts, conveniently spoken of as head, body, and tail (see Fig. 90). Each of these is usually markedly trilobed, having a central axis, separated by furrows from the side parts. In the head the axial part is known as the glabella. It may be expanded in front or behind, and may be plain or marked by one or more pairs of furrows which rarely cross the glabella. The lateral portions of the head are spoken of as cheeks. Each cheek is

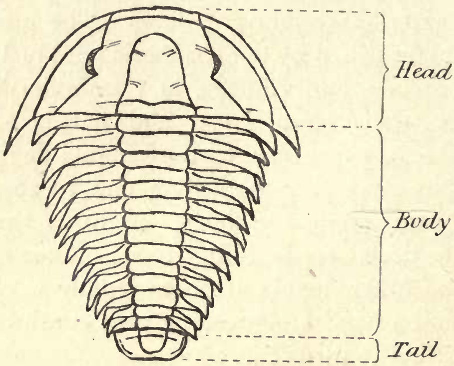


FIG. 90.

A TRILOBITE (*Olenus*).

The central bell-shaped portion of the head is the glabella, with two pairs of glabella furrows indicated by the paired lines sloping obliquely inwards. The rest of the head forms the cheeks, which are divided by the facial sutures—one on each side. In the figure these extend forwards from the crescentic eyes to the front of the head, and also curve backwards from the eyes to the hinder margin of the head.

usually divided into two parts by the facial suture which, cutting the upper part of the head in front, passes backward, and terminates either at the side, the angle, or the hind margin of the cheek. When eyes are present, they are situated on the free cheek, the fixed cheek being attached to the glabella and separated from it by a furrow. The hinder part of the head consists of a neck-furrow behind the glabella, with a corresponding ridge usually continued on the cheeks. This is sometimes mistaken by beginners for a body segment, which it resembles, but differs by being soldered to the rest of the head. The posterior angle of the head may be rounded or prolonged into spines.

The body is composed of separate body rings varying in number from two to over twenty, though not often less than eight or more than fourteen. The axis of each ring is separated from the side or pleuron by a furrow. The pleura may be grooved or more rarely ribbed. The ends may be rounded or terminated in spines. In some cases they are modified by the possession of facets, allowing one to slip beneath the other, in which case the animal could roll itself up like a woodlouse.

The tail is composed of a number of coalesced segments forming one piece. Each segment may, and often does, generally resemble a body ring, but differs from it inasmuch as the lines which represent divisions between the segments of the tail do not reach the margin. The tail may be rounded, or the median axis may be prolonged into a spine. In some trilobites a fringe of spines surrounds the tail.

The Cambrian trilobites usually possess small tails of a few coalesced segments, and are not modified for rolling up. The facial suture, save in the case of certain trilobites of the Tremadoc slates, cuts the posterior margin of the head.

The trilobite which is figured belongs to the genus *Olenus*, which is characteristic of the Lingula flags.

In addition to this the student who has access to collections may well examine the following Cambrian fossils.

Hymenocaris . } Lingulella Davisii }	Lingula Flags.
Paradoxides .	Menevian and Harlech Beds.

THE ORDOVICIAN SYSTEM

The rocks of the Ordovician system are mainly developed—(i) in Wales, around the rocks of the Cambrian system of North and South Wales, and also in smaller inliers in various parts of the Principality; (ii) in the Welsh borders and adjoining English counties; (iii) in Cumberland and Westmorland; and (iv) in parts of the Southern Uplands of Scotland; also (v) in many parts of the outer rims of Ireland. They are divided into the following series:

Bala or Caradoc Beds.
Llandeilo Beds.
Arenig Beds.

Lithologically they resemble the Cambrian beds in the abundance of slates, and to some extent of grits, though they differ from these Cambrian beds in the very great amount of volcanic matter in the form of lavas and ashes which is intercalated with the ordinary sediments. These volcanic rocks are chiefly found in the Arenig and Bala rocks of North Wales and the Welsh borders, and in the

Llandeilo rocks of the Lake District. As the soils to which they give rise are not very different from those of the Cambrian sediments, their main importance, from the agricultural point of view, is that, owing to their durability, they have resisted denudation, and are responsible for much of the upland wastes of England and Wales. Snowdon and its attendant peaks in North Wales, and the Scawfell group of hills in Cumbria, are formed of volcanic rock. Thin bands of limestone occur in the Llandeilo and Caradoc rocks of Wales, the Welsh borders, the Lake District, and the Scotch Southern Uplands.

The section (Fig. 91) drawn from the shores of the Menai Straits across Snowdon will give the student an idea of the relationship of the Ordovician and Cambrian rocks, and show the manner in which the hard volcanic rocks in the centre of the syncline have affected the character of the country.

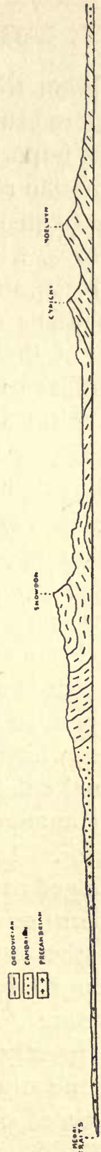


Fig. 91. Section from Menai Straits across Snowdon.

The fauna of the Ordovician rocks is more varied than that of the Cambrian system. Trilobites and brachiopods are still very abundant. The former are more highly organised than those of the Cambrian system. The size of head, body, and tail is usually more nearly equal than in the case of the

Cambrian trilobites, and the segments of the body are more compactly knit together.

An important feature wherein the fauna of the Ordovician rocks differs from that of Cambrian strata is the frequency of graptolites in the former. These creatures, which are now generally referred to the Hydrozoa, and are believed to be allied to the modern sertularians or "Sea Firs," formed hard parts composed of the horny substance known as chitin, which is familiar to us as covering the bodies of butterflies; this chitin is usually replaced by a carbonaceous material, or by iron pyrites or other mineral, in the fossil remains of graptolites. Fig. 92 exhibits two graptolites which will give the reader a general idea of their appearance. A dagger-shaped sicula—the pointed top of Fig. 92 (A), which is concealed in Fig. 92 (B)—forms the hard covering of the young graptolite. From this originates a common canal surrounded by its hard covering or periderm, arranged lengthways, and parallel to the canal is a row of cells or hydrothecae, which doubtless contained the polypites of the original colony. These cells had a connection with the common canal, and also an opening to the exterior. In certain graptolites a chitinous rod—prolonged at the top of Figure 92 (B)—ran along the periderm on the side opposite to that on which the hydrothecae occurred, and is frequently seen to be prolonged beyond the cell-bearing portion of the graptolite. The branches or stipes of the graptolites vary greatly in number; some graptolites possess only one stipe, others two, four, and multiples of four, sometimes exceeding thirty. These stipes may or may not be attached to one another. In Fig. 92 (A) the two stipes are unattached; in Fig. 92 (B) they are attached, so that each side of the "polypary" is celluliferous, and the chitinous rod passes through the centre of the fossil. We rarely find four coalesced

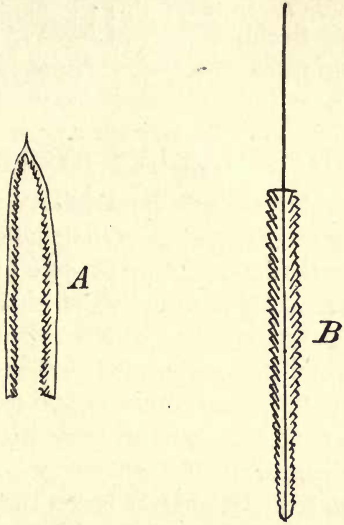


FIG. 92.
GRAPTOLITES.
A = *Didymograptus.* B = *Diplograptus.*

stipes, but never more. The character of the hydrothecae varies greatly; in the earlier graptolites they are usually simple rectangular tubes, while in later forms they are often very complicated. Fig. 92 (A) represents *Didymograptus*, which is characteristic of the Upper Arenig and Llandeilo rocks, while 92 (B) shows a *Diplograptus*, which ranges from the Arenig rocks to the top of the Ordovician and into the lowest Silurian strata.

The following are names of other Ordovician fossils which the student may with advantage examine :—

Trinucleus concentricus	Caradoc Beds.
Asaphus tyrannus .	Llandeilo Beds.
Ogygia Buchii . .	Llandeilo Beds.
Tetragraptus . .	Arenig Beds.

THE SILURIAN SYSTEM

The rocks of the Silurian system received their name because they were first studied in detail in the country of the Welsh borderland, once occupied by the ancient tribe of Silures. The lithological characters of the strata in this region are somewhat different from those which the strata present in other British areas. The other chief areas where strata of this age are developed are (i) a strip of country stretching southward from the estuary of the Conway in North Wales, extending to the east of Bala Lake, and south of this widening out to include the greater part of Central Wales, from the Welsh borderland to the coast and as far south as the Ordovician strata of Pembrokeshire and Carmarthenshire; (ii) the southern half of the English Lake District; (iii) a great part of the Southern Uplands of Scotland. The rocks of the system mainly consist of grits and slates, having a general resemblance to those of the Cambrian system, and containing little recognisable volcanic material. In the district of the Welsh borderland there are important bands of limestone.

The Silurian rocks are divisible into the following series:—

Ludlow Beds.
Wenlock Beds.
Llandovery Beds.

The principal calcareous beds are found in the middle of the Wenlock series. Some of this limestone is largely composed of corals, which formed reefs in the Silurian sea.

The Silurian strata, on the whole, give rise to less elevated ground than do the Cambrian and Ordovician rocks, and accordingly more cultivation is carried on in Silurian districts than in those occupied by the older rocks, but much of the country is waste land, available only for sheep-grazing, as, for instance, the hills of the Southern Uplands of Scotland; those lying west of the Lake District proper, known as the Howgill Fells; also those which occupy the greater portion of Central Wales.

The fauna of the Silurian rocks does not depart very widely from that of the Ordovician strata. The trilobites are still more highly developed than those of Ordovician times, and the facial suture of many ends on the outer margin of the cheek. Several were modified so that the creature could roll itself up, and their remains are often found so rolled. The graptolites are chiefly forms consisting of one stipe, with a chitinous rod extending along the back of the periderm, the commonest genus, which practically ranges through the system, being of this nature; it is termed *Monograptus*. Corals, as already mentioned, are abundant in the limestones (for description of coral see p. 250). The remains of crinoids, or sea-lilies, are also very frequent in these limestones. Some reference to the character of the hard parts of these organisms which are most frequently preserved will be found in a later chapter. The tests of brachiopods are again abundant. These organisms, formerly placed with the Mollusca, to some extent play their part, for we find that, as we pass from older to newer strata, the proportion of brachiopods diminishes, while that of the Mollusca increases. The brachiopods secreted a shell consisting of two valves, which in one group (*Inarticulata*) are connected by muscles only; in this group the shells are often horny. The genus Lingula represents it. The other group (*Articulata*) contains brachiopods in which the valves are connected by projections, or "teeth," on one valve, fitting into sockets in the other. The shells of this group are calcareous. The shells of brachiopods are inequivalve, one valve being of different shape from the other, while each valve is usually equilateral, being divisible by a straight line down the centre into two equal parts. The valves are dorsal and ventral, the latter being the larger, and prolonged at the anterior end into a beak or umbo, often perforated by a foramen (*f*, Fig. 93). An internal calcareous structure, often consisting of a loop or of spirals, is found in many brachiopods. Fig. 93 represents *Atrypa reticularis*, a brachiopod which is very abundant in Silurian rocks, though it passes upward into those of the Devonian system. The true molluscs are fairly abundant in the different series of the Silurian rocks. Vertebrates first appear in these rocks, the earliest British vertebrates, consisting of fish-remains, having been detected rarely in the Lower Ludlow strata; they are more abundant in the Upper Ludlow rocks, and at one horizon are so frequent as to give rise to a "bone-bed," containing numerous fragments of the bones and teeth of fishes.

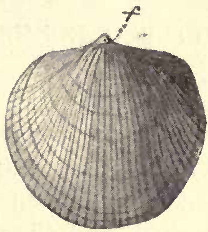


FIG. 93.
Atrypa reticularis.
f = Foramen in beak of ventral valve.

The following is a list of some characteristic Silurian fossils:—

Fossil	Beds
Chonetes striatella	Ludlow Beds.
Monograptus colonus	Ludlow Beds.
Halysites catenularius	Wenlock Beds.
Favosites gothlandica	Wenlock Beds.
Calymene Blumenbachii	Wenlock Beds.
Phacops caudatus	Wenlock Beds.
Rastrites peregrinus	Llandovery Beds.
Pentamerus oblongus	Llandovery Beds.

CHAPTER XVIII

THE UPPER PALÆOZOIC ROCKS

THE occurrence of important earth-movements at the close of Lower Palæozoic times has already been noticed. These movements were important on account of their effects (i) upon the rocks already deposited, and (ii) upon those which were accumulated during the period of movement.

The rocks already formed were thrown into a series of anticlinal and synclinal folds, having their axes running in a general east-north-east and west-south-west direction: and as the result of continued pressure, changes were induced in the rocks, causing their hardening, and in many cases impressing upon them the cleavage-structures which converted the finer sediments into slates. The anticlinal folds gave rise to elevated ground which underwent denudation, and the denuded material was accumulated in the intervening and adjacent depressed areas. Owing to these movements, therefore, the sediments which were deposited at the commencement of Upper Palæozoic times were laid down in sheets which were only formed over parts of the area; and where they were accumulated they frequently possessed somewhat abnormal characters as compared with ordinary marine sediments. As the earth-movements seem to have decreased in intensity southward, these abnormal sediments are replaced by normal marine deposits in the extreme south-west of England. The rocks of this period are spoken of as belonging to the Devonian system, and they must now be considered.

THE DEVONIAN SYSTEM

The normal marine sediments of the Devonian age are found in Devon and Cornwall, on either side of a strip of Carboniferous rocks running east and west, which occupies the centre of a synclinal fold in Mid-Devon. They are largely argillaceous and arenaceous, though a considerable amount of limestone is found, especially in South Devon, in the neighbourhood of Torquay and Plymouth. As these Devonian rocks at a much later period were affected by powerful earth-movements which became less potent further north, they also are often affected by structures impressed upon them subsequently to their deposition, and of these structures cleavage is noteworthy. Though the rocks to some extent resemble those of the slate districts of Wales, the amount of land under cultivation in Devon and Cornwall is much greater than in most of the Welsh counties, for while a little more than forty per cent. of the area is waste, nearly sixty per cent. is under cultivation—about thirty-eight per cent. as arable land and a little over twenty per cent. as permanent pasture.

In considering the relationship of the rock-structure of these counties to the fertility of the soil, the existence of great masses of intrusive granites occupying a large part of the south of the counties must not be overlooked. These granites give rise to soil which, though often barren at high levels, is very prolific at lower elevations.

The attempt to classify the Devonian rocks into series is somewhat difficult, and the student need not be troubled with the minor subdivisions into series, the exact position and value of some of these being still a very uncertain matter. It will be sufficient for him to remember that the rocks are usually separated into upper, middle, and lower divisions. Of these the Lower Devonian rocks consist largely of sandstones with associated slaty deposits, and the Middle Devonian strata contain the principal developments of calcareous matter, which are frequently found in huge node-like masses rapidly dying out in all directions, and when studied in detail are often seen to be composed to a considerable extent of reef-building corals. A fair amount of volcanic matter is also associated with the Middle Devonian strata of South Devon. The Upper Devonian rocks, like the Lower, consist essentially of sandstones and slates, though there is a fair proportion of calcareous sediment associated with the mechanical sediments of this age in South Devon.

The abnormal sediment of the Devonian age is spoken of as belonging to the Old Red Sandstone type. It now occurs in isolated patches in Great Britain and in outlying patches and long strips in Ireland.

The most northerly of these patches in Great Britain occupies the Orkney Isles, a considerable part of Caithness, and the strip of coast southward to Moray Firth. The next large mass occupies parts of the great Central Valley between the Highlands and the Southern Uplands, and flanks the Carboniferous strata which occupy the central portion of this valley. A tract of Old Red Sandstone of some importance occupies part of the Cheviot Hills.

A very important tract commences near Bridgnorth, in Shropshire, extends over a considerable part of Herefordshire and Brecknockshire, and sends off two spurs, one to the south-west to Cardiff and the other to the west through Carmarthenshire and Pembrokeshire.

In Ireland the principal development of the Old Red Sandstone is in the south, in Cork and Waterford.

The Old Red Sandstone is usually separated into upper and lower divisions. Each consists in the main of quartzose sandstone, coloured red with a coating of oxide of iron around the constituent grains of the rock. Shales and conglomerates occur, intercalated with the sandstones at different horizons. In the Lower Old Red Sandstone numerous beds of nodular limestones, known as "cornstones," are found interstratified with the sandstones, as over large parts of Herefordshire, and the lower division is sometimes known, therefore, as the Cornstone group. In parts of the Upper Old Red Sandstone series yellow and brown sandstones frequently predominate over the red beds.

The mode of formation of the Old Red Sandstone is still a topic for discussion; while some writers consider that it had a lacustrine origin, others refer it to deposit under shallow-water marine conditions.

The Old Red Sandstones furnish good building-stone, and the well-known Caithness flagstones belong to these rocks.

The soil produced from the Old Red Sandstone is often a strong loam of considerable fertility. Much is devoted to pasture, and many orchards and some hop-yards are found in the Old Red Sandstone country, especially in Herefordshire, where the cornstones form the richest soil. In many places, however, the soil over this deposit is boggy, and therefore not particularly productive.

The fauna of the Devonian rocks differs in some respects from that of the Lower Palæozoic strata. Corals are, as already pointed out, abundant in places, and give rise to important masses of limestone. It will be convenient if the student is here given a brief account of some of the characters of the hard parts of corals. The corals belong to the Actinozoa, which also includes the sea-anemones. The hard parts of a simple coral, which are composed of carbonate of lime, show a more or less close approximation to radiate symmetry. The whole of the hard part is termed the corallum, and in a simple coral is composed of one corallite, while a compound coral consists of two or more corallites. The typical simple coral is of conical form, with a cup-shaped depression or calyx at the widest part of the cone. The outer wall of the corallum is the theca, which encloses a chamber divided by partitions; of these the first to be noticed are the septa, which are vertical plates extending from the theca towards the centre of the chamber within the theca. Some reach the centre, while others only extend part of the way, and in some corals the septa are rudimentary. They are arranged in multiples of four or six, and

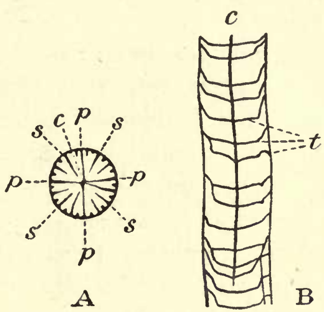


FIG. 94.

A = Transverse, B = Longitudinal sections across a coral (*Lithostrotion*).

c = Columella.
p = Primary } septa.
s = Secondary } septa.
t = Tabulae.

the principal septa are termed primary; next in importance are the secondary, and there may be tertiary and even higher multiples. In Fig. 94 a diagrammatic representation of primary septa (*p*) and secondary septa (*s*) is shown in a cross-section of a coral. In Palæozoic corals the septa are generally in multiples of four, while in the later corals they are usually in multiples of six. A vertical calcareous rod, the columella, is found in the centre of the chamber of many corals. In a longitudinal section, as seen in the diagram 94 (B), other calcareous plates arranged more or less transversely across or partly across the chamber may be seen. Those which extend right across the chamber or nearly so are termed tabulae, while others which extend partly across uniting adjacent septa are termed dissepiments.

A very common Devonian coral is *Pachypora cervicornis*, in which the septa are rudimentary, while the tabulae are very regular. This coral is compound, consisting of a number of polygonal corallites, so arranged as to present the appearance of deer's antlers when the coral is cut longitudinally; hence the specific name. Another remarkable Devonian coral is *Calceola sandalina*, which resembles the pointed extremity of an antique slipper. It is chiefly noteworthy for the occurrence of a calcareous operculum which closes the calyx, a very exceptional structure among the corals.

The trilobites of the Devonian rocks are characterised by the possession of spines in many species. Some of the more ancient trilobites were very spinose, but the proportion of spinose trilobites among the Devonian rocks is unusually large. This is probably one of the signs of approaching extinction of the group.

A group of organisms related to the modern king-crab is found rather frequently in the Old Red Sandstone rocks. *Pterygotus problematicus* is a representative of this group.

The most remarkable fossils of the Old Red Sandstone are vertebrates. Some of these are armoured fish with a bony covering to the whole or part of the body. Some of these vertebrates have now been separated from the fishes and placed in a different group, the Agnatha. *Cephalaspis* is a genus which is frequently found in the Devonian strata.

Besides the organisms already mentioned, the following Devonian fossils may be enumerated :—

Cucullæa Hardingi . .	Upper Devonian.
Stringocephalus Burtini .	Middle „
Pleurodictyon problematicum	Lower „

THE CARBONIFEROUS SYSTEM

The rocks of this system are divisible into lower and upper portions. Those of England and Wales may be conveniently referred to two great axes of uplift, viz. the north and south Pennine anticline in the north and centre, and the east and west Mendip anticline in the south. These anticlines consist chiefly of Lower Carboniferous rocks, and are flanked on each side by the rocks of Upper Carboniferous age. In the north we find the Carboniferous rocks occupying a large part of Northumberland and Durham, and extending in a girdle round the slate rocks of the Lake District. They occupy the fell-region of West Yorkshire and East Lancashire, and the dale district of Derbyshire, where they pass below the Triassic rocks of the midland plain, though "islands" project through this, forming various midland coalfields. A discontinuous strip flanks the east side of the older rocks of Wales. In the south, the South Welsh coalfield and the coalfields of the Forest of Dean and Bristol lie on the north side of the Mendip area, while some way to the south of it is the somewhat abnormal development of Carboniferous rocks of Central Devon.

In Scotland the main district occupied by Carboniferous rocks is in the drainage areas of the Forth and Clyde, in the centre of the Great Valley, and, as

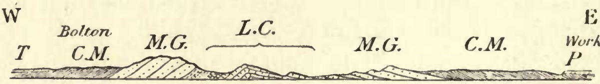


FIG. 95.

SECTION ACROSS THE PENNINE CHAIN FROM THE LANCASHIRE COALFIELD TO THAT OF YORKSHIRE.

(Length about 40 miles.)

T=Trias. *P*=Permian. *C M*=Coal-measures.
M G=Millstone Grit.
L C=Lower Carboniferous strata (Limestones and Shales).

before stated, these rocks are flanked to the north and south by strata of the Old Red Sandstone.

In Ireland the central plain is largely composed of Lower Carboniferous rocks, for the Upper Carboniferous rocks have been almost entirely removed by subsequent denudation, though isolated patches have been left, forming the coalfields of Clare, Limerick, and Cork, and the Leinster coalfield in the south, and those of Leitrim, Tyrone, and Antrim in the north.

The mode of occurrence of the coal-measures in basins is well shown in a section taken across the Pennine chain from the Lancashire coalfield to that of Yorkshire, as represented in Fig. 95.

The lithological characters of the Lower Carboniferous rocks differ in a marked degree over great parts of Britain from those of the Upper Carboniferous rocks. The following is the classification of the beds:—

Carboniferous	Upper	Upper	Coal-measures.
		Middle	
		Lower	
		Millstone Grit.	
	Lower	Upper Limestone Shales.	
		Mountain Limestone.	
		Lower Limestone Shales, Sandstones, and Conglomerates.	

The Mountain Limestone forms the main division of the Lower Carboniferous rocks, as the upper and lower shales are often thin, and when thick may be intercalated with calcareous beds. The limestones are frequently massive, of a grey colour, and in many places of a high degree of purity. The well-known dale districts of Derbyshire and the West Riding of Yorkshire and the Mendip ridge show the type of country formed of this rock in a characteristic manner. The drainage is largely underground, and the limestone often gives rise to bare plateaux and escarpments.

In Northumberland the Lower Carboniferous rocks are largely composed of mechanical sediments, and coal-seams occur in them. In Scotland some of the beds of this age are of fresh-water origin, while in Devonshire the thin Lower Carboniferous strata are partly composed of radiolarian cherts. Much of the

Lower Carboniferous country of Ireland is occupied by bog.

The limestones are of organic origin, some being formed largely of reef-building corals, though the most noteworthy of the limestones consist to a large extent of fragments of crinoids or sea-lilies.

The soil of the Lower Carboniferous rocks where composed of limestone is often very thin, if indeed it be not altogether absent; but where the limestone has been mixed with mechanical impurities, these are left behind after the solution of the upper parts of the limestone, usually giving rise to a ferruginous loamy soil, which is often covered with short sweet turf so characteristic of calcareous formations in Britain. This forms good grazing ground for sheep and cattle, as is well exhibited in the case of the calcareous districts of the West Riding of Yorkshire about Skipton and Settle.

The argillaceous development of the Lower Carboniferous rocks is frequently occupied by rushy waste land, due to the impervious nature of the underlying rocks.

Sandstone is the dominant rock of the Upper Carboniferous strata. The Millstone Grit consists almost exclusively of coarse yellow sandstones, though thin seams of shale are intercalated with them. The sandstones of the coal-measures are usually finer than those of the Millstone Grit. Shales are also found with them, though the most interesting deposits are the coal-seams and their underclays, and certain bedded ironstones.

The nature of coal has been briefly noticed in

Chapter V. There is no doubt that the Carboniferous coal is of vegetable origin, and that it is mainly composed, as previously stated, of lycopodiaceous plants, now represented by the club-mosses, many of which reached a gigantic size in the Carboniferous period.

The underclays which occur below many seams are certainly of the general nature of soils; they are often penetrated by rootlets, and like other soils, their alkaline constituents have been largely extracted; hence their value as fire-clays, owing to their relative infusibility.

The coal-seams appear to have been formed by the growth of vegetation on flat, marshy ground, in an area of considerable humidity.

Among the economic products of the coal-measures besides coal and fire-clay, we may mention lime from the Lower Carboniferous Limestone and building-stone from most of the divisions. Iron ore occurs in strata in Staffordshire and Scotland, and in fissures in the Mountain Limestone of the Furness district of Lancashire. Lead is often found in veins in the Mountain Limestone, as in Cumberland, Yorkshire, Derbyshire, and Flintshire. The soil of the Millstone Grit is usually very unproductive, and the Millstone Grit gives rise to moorland country. The soil of the coal-measures is also usually barren, though there are exceptions to this, especially upon the lower grounds occupied by deposits of this age.

The flora of the Carboniferous rocks is one of flowerless plants. Besides Lycopods, Equisetaceae (horsetails) and ferns are abundant.

The fauna is a varied one. The great groups of invertebrates are well developed, and among the vertebrates we find many fish and also some amphibia, though the latter are far from numerous.

The abundance of crinoids in the limestones has already been noted. The structure of these creatures, which appertain to the Echinodermata and are allied to the echinids or sea-urchins of our shores, is complicated, and as complete specimens are somewhat rare, it will be unnecessary to give an account of the structure. It will be sufficient to state that the greater number of extinct crinoids possessed a calcareous stem, consisting usually of a large number of circular or five-rayed plates perforated in the centre, and often marked by ridges or furrows around the margin. It is these stem-plates which contribute very largely to the crinoidal or encrinital limestones. As the ligament which passed through the perforated centres frequently decomposed before the creature was embedded, the plates are frequently separated, or clusters of a few attached plates are found still connected. The general appearance of these crinoid plates is shown in Fig. 96.

Among the corals of the Mountain Limestone we may mention *Lithostrotion basaltiforme*, which consists, as its specific name indicates, of corallites of polygonal outline resembling small basaltic columns, and *Syringopora*, consisting of tubular corallites which are not in contact, and are arranged in subparallel groups, adjoining corallites being connected at intervals by small transverse tubes. Brachiopods are still abundant, the genera *Producta* and *Spirifera*, though by no means confined to the Carboniferous system, being very frequent in its strata. Trilobites are rapidly disappearing, only a few genera occurring in the rocks of this system, and their remains are rare.

Of the molluscs, most of the important groups are well represented. Among the coal-measures, bivalve Mollusca somewhat similar to the modern fresh-water mussel are common, and they suggest fresh-water origin, for some, at any rate, of the beds of the coal-measures.

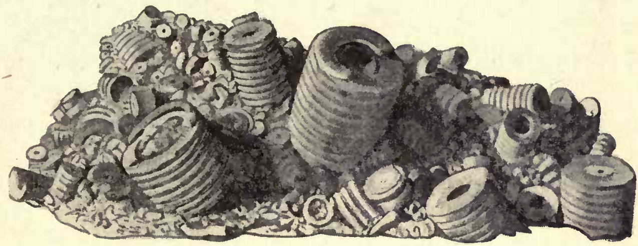
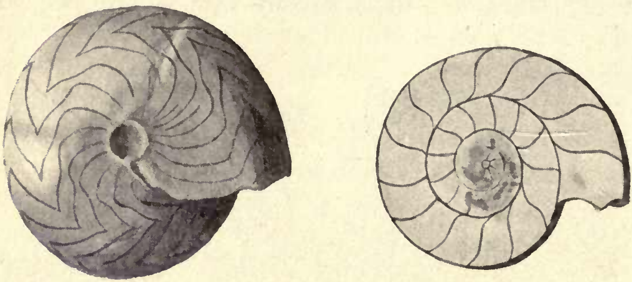


FIG. 96.

CRINOID PLATES IN LIMESTONE.

The great group of Cephalopods is represented by many forms. These, the highest of the Mollusca, are divided into two orders—one containing the cuttle-fish and the other the nautilus. The latter division is characterised by the possession of a shell having certain structures which may be noticed at this point. Fig. 97, showing the shell of *Goniatites*, a frequent Carboniferous cephalopod, as seen both from the exterior, with the shell removed (A), and in cross-section (B), will serve to illustrate the nature of a cephalopodous shell.

The shells of the Cephalopoda may be regarded as elongated cones, which may be straight or coiled in various spirals. In *Goniatites* the shell is coiled in a discoid spiral, *i.e.* a spiral in which all the whorls are in one plane, as opposed to a helicoid spiral, like that of a snail-shell, in which the whorls are not in one plane. The cavity of the shell is divided into chambers by calcareous partitions or septa, and the chambers



A B

FIG. 97.

A GONIATITE.

A. Internal cast showing sutures.
B. Cross section showing septa (the siphuncle is not seen).

increase in size as the aperture of the shell is approached. These septa are pierced by a tube or siphuncle, which may occur on the inner or outer margin of the shell, or may be central. In *Goniatites* the siphuncle is on the external margin; it is not shown in Fig. 97 (B).[1]

The septa may be simply curved, or the parts adjoining the shell wall may be folded and puckered in various ways. If the shell be stripped off a fossil

[1] For *siphuncle* see Fig. 98, p. 275.

and a cast of the interior left, as in Fig. 97 (A), the outer rims of the septa will appear as lines on the cast. These are known as sutures, and by them the Cephalopods of different ages may be to some extent recognised. If the folds in the septa are simple, the sutures will also be simple; if very complex, the sutures will be complex. In *Goniatites* the sutures are usually angular, as shown in Fig. 97 (A), or they may be slightly rounded at the angles; whereas, as we shall find when we consider the ammonites of the Mesozoic rocks, the sutures of those shells are usually much more complicated.

In addition to the fossils of the Carboniferous rocks which have already been enumerated, the following may be mentioned:—

Calamites	Plants of the Coal-measures.
Sigillaria, with its roots, Stigmaria . . .	
Phillipsia	Lower Carboniferous.
Euomphalus pentangulatus	

THE PERMIAN SYSTEM

Although the beds of the Permian system are placed among the Primary strata, and the Triassic rocks are included among the Secondary strata, the British Permian rocks are separated from those of Carboniferous age by a great physical break—an unconformity—while the unconformity between Permian and Triassic rocks, when present, is but slight. We accordingly find the Permian rocks resting upon the upturned edges of the Carboniferous strata, as shown in the section, Fig. 95, while their prevalent strike conforms with that of the Mesozoic strata of the east of England.

As the result of the uplifts at the close of Carboniferous times the British area was once more under essentially continental conditions, and the prevalence of a dry climate caused the area to be arid, thereby affecting the nature of the rocks of Permian and Triassic ages, which are largely of the nature of desert accumulations.

The principal strip of Permian rocks extends from the mouth of the Tyne southward to Nottingham. Less extensive developments are found on the west of the Pennine chain in the Eden Valley and near Manchester, and some small patches occur here and there in the midland and southern counties.

The succession of the rocks is as follows :—

Magnesian Limestone.
Marl Slate.
Lower Permian Sandstones.

The Lower Permian Sandstones are not well developed on the east, but attain a considerable thickness in the Eden Valley, where they form the great bulk of the Permian strata, and are coloured red by iron oxide.

The Marl Slate is usually quite thin, and of little importance in affecting the soil. It is not a true slate, but a muddy deposit.

The Magnesian Limestone is composed of varying amounts of carbonates of lime and magnesia. It attains its principal development in Durham and

Yorkshire; in Nottinghamshire it passes into a sandstone cemented by an infiltration of the carbonates of lime and magnesia.

The Permian rock furnishes good building-stones in places. The Penrith Sandstone of the Eden Valley is largely used for this purpose, as is also the sandstone development of the Magnesian Limestone series about Mansfield, in Nottinghamshire.

The Lower Permian Sandstones are marked by a considerable amount of waste land. The Magnesian Limestone when pure gives rise to a light, dry, arable soil.

The fauna of the British Permian rocks is naturally poor. The principal fossils occur in the Magnesian Limestone, and furnish evidence that this deposit was laid down in a sea which was shut off from the main ocean, for the fossils are stunted, and though individuals are abundant, they belong to few species. The fauna may be looked upon as the surviving relic of the Carboniferous fauna. Among the British fossils may be mentioned a brachiopod, *Producta horrida*, and a bivalve mollusc, *Schizodus obscurus*.

CHAPTER XIX

THE SECONDARY ROCKS

THE Secondary rocks of England were deposited with no great break upon the Permian rocks, when the latter occur. Their distribution in the east and south-east of England, east of a line drawn from the Tees to Torbay, has already been noticed. They have a prevalent strike from north-north-east to south-south-west over a great part of this tract, but the strike is approximately east and west through several of the southern counties. They dip usually at low angles towards the North Sea, except in the south, where they are thrown into anticlinal and synclinal folds, of which the most important is the great Wealden anticline or elongated dome. The rocks are of very varied characters, and they consist essentially of marine strata, with the significant exception of the strata of the lowest system.

The country occupied by Mesozoic rocks consists of two important strips of elevated ground with escarpments facing westward, each overlooking a plain to the west, and dip-slopes sinking eastward. Commencing in the west, we meet with the Triassic plain of central England, which is overlooked by the great escarpment of the Lower Jurassic rocks. The Upper

Jurassic rocks form another plain, which in one place expands into the fenland, and this is flanked to the east by the Cretaceous escarpment. A minor plain, that of the Gault, is sometimes emphasised by the local importance of the high ground of Lower Cretaceous age, and it is bounded to the east by the escarpment of the chalk.

The dependence of the character of the ground upon the underlying formations in the area of England occupied by Mesozoic strata is well shown in the section No. 2 in Fig. 89.

THE TRIASSIC SYSTEM

As the physical conditions which prevailed over the British area in Permian times were as a whole continued through the greater part of the Triassic Period, the lithological characters of the Triassic rocks have much in common with those of Permian times, red sandstones being the prevalent strata.

The Triassic rocks are very widely distributed in England. They occupy a great part of the Central Plain, in the counties of Stafford, Shropshire, Worcester, and Warwick. This plain is continued northward as a narrower strip through Nottingham and Yorkshire into Durham, and southward to Gloucester, East Somerset, and East Devon, while a spur is sent from the north-west end of the Central Plain into Cheshire and West Lancashire. The eastern part of the Eden Valley and the plain of the Vale of Clwyd, in North Wales, are also composed of Triassic strata.

The classification of the British Triassic rocks is as follows:—

Rhætic.

Keuper { Keuper Marls.
Keuper Sandstones
(unconformity).

Bunter { Upper Red and Mottled Sandstone.
Pebble Beds.
Lower Red and Mottled Sandstone.

The nature of the Bunter beds is almost sufficiently explained by the names assigned to them. The sandstones are usually soft, false-bedded, bright red deposits with occasional breccias. They are occasionally of sufficient hardness to be used for building purposes. The pebble beds often consist of a brown sandstone, with a varying proportion of well-rounded pebbles, of which the dominant rock is quartzite.

The Bunter beds are usually, if not always, separated from those of Keuper age by an unconformity, and numerous local unconformities occur in the centre of both Bunter and Keuper deposits, as might be expected in a group of deposits which were accumulated under continental conditions. Many of the sandstones yield evidence of having originated as dunes blown by the wind and piled up on the floor of the desert.

The Rhætic beds, which are classified with the Triassic rocks, are marine sediments of very constant characters. They more closely resemble the Jurassic rocks, but being very thin are of no great importance from a practical standpoint.

The economic importance of some of the products of the Triassic rocks is considerable. Good building-stones are found among the sandstones of Keuper age, and Cheshire and the adjoining counties have long been celebrated for the abundance of rock-salt, which is intercalated with the mechanical accumulations of the Keuper marls. Gypsum is found in several places. The so-called marl itself is exceedingly important, being used for marling land occupied by other strata.

The Bunter beds cause a considerable amount of waste land, especially the Middle Division—the pebble beds; but even these have been rendered fertile by means of marling, the marl being brought, as stated, from the adjacent Keuper deposits.

Much of the New Red Sandstone ground is now arable land, and it also furnishes rich meadow and pasture land. The cattle which supply the milk for Cheshire cheeses, for example, are reared upon this land.

The marls form ground which is adapted for orchards and also for the growth of teazles.

The fauna of the British Triassic strata, apart from the Rhætic beds, is even poorer than that of the Permian rocks. With the exception of a few poorly preserved shells, the principal fossils are those of amphibia and reptiles.

The latter first appeared in the Permian strata, and became very abundant among the Mesozoic rocks. It is unnecessary to enumerate any of the fossils of the British Triassic beds.

THE JURASSIC SYSTEM

The rocks of the Jurassic system are chiefly found occupying a strip of country extending from the Yorkshire coast to that of Dorsetshire. Some outlying patches exist in the north and west of Scotland and in the north-east of Ireland. As the rocks of this system are very varied, and many of them give rise to soils of great fertility, it will be necessary that the student should consider their classification in somewhat greater detail than in the case of the rocks of the systems which have hitherto been considered.

The following classification will suffice :—

- Oolites
  - Upper Oolites
    - Purbeck Beds.
    - Portland Beds.
    - Kimmeridge Clay.
  - Middle Oolites
    - Corallian Beds.
    - Oxford Clay.
    - Kellaway Rock.
  - Lower Oolites
    - Cornbrash.
    - Forest Marble and Bradford Clay.
    - Great Oolite.
    - Fuller's Earth.
    - Inferior Oolite.
- Lias . . .
  - Upper Lias.
  - Middle Lias or Marlstone.
  - Lower Lias.

The Lias beds rest conformably upon the Rhætic beds of the Triassic system, but the Cretaceous beds in most parts of the line of junction with the rocks of the Jurassic system repose upon the latter in an unconformable manner.

The predominating strata of this system are more or less consolidated muds, which attain their maximum development in the case of the Lias, Oxford Clay, and Kimmeridge Clay. Separating these clayey deposits are limestones and sandstones, the latter being sometimes pure quartzose sands, though they are often ferruginous or calcareous. The oolitic limestones are most largely developed in the group of the Lower Oolites, though they are by no means exclusively confined to them.

The Liassic beds commence near Whitby in the north, and are exposed at the bottoms of several of the valleys among the moors of East Yorkshire. They run southward, forming a comparatively narrow strip in Yorkshire and Leicestershire; but this strip widens in Leicestershire, Northamptonshire, and Warwickshire, to contract once more further to the south. Owing to the argillaceous character of the beds, the country occupied by them is largely of the nature of plain, and forms an eastward continuation of the Triassic plain.

The Middle Division of the Lias, as its title Marlstone implies, is more calcareous than the Upper and Lower Divisions. The latter consist essentially of clay, with intercalations of impure limestone often occurring in disconnected nodular masses. The Middle Division, on the other hand, contains much limestone, often iron-stained, and there are frequent beds of sandstone.

The Lower Oolites are very variable. In the south-western counties of Dorsetshire, Somersetshire, and Gloucestershire the beds are largely calcareous, the Inferior Oolite limestone and the Great Oolite limestone being important members of the series. At the base of the Inferior Oolite of these counties occurs a deposit of micaceous sandstones which is often calcareous. These sandstones are called the Midford sands. The Inferior Oolite limestone is oolitic in texture and often iron-stained. It has intercalated beds of sands and marls.

The Fuller's Earth is formed of clay and marl with some clayey limestone.

The Great Oolite is a yellowish oolitic limestone, with occasional marly partings. At its base in Oxfordshire is a laminated calcareous sandstone, which is used for roofing purposes; it is termed the Stonesfield slate, though it is not a slate in the technical sense of the word.

The Forest Marble contains a great variety of muddy, sandy, and limy beds, though an oolitic limestone forms its principal deposit. In some places it appears to be replaced by a clay, the Bradford Clay.

As one passes to the north from the south-western counties, the Lower Oolites undergo a marked change, as the calcareous deposits disappear and are replaced by estuarine sands, which are known as Northamptonshire Sands in that county, and are spoken of as the Estuarine series in Lincolnshire and Yorkshire. In Northamptonshire the Estuarine beds represent the Inferior Oolite and the lower part of the Great Oolite, the upper portion of this series being still represented by marine limestones and clays; but in Lincolnshire and Yorkshire these also are replaced by estuarine sands. In Lincolnshire, however, part of the Inferior Oolite is represented by a marine oolitic limestone known as the Lincolnshire Limestone, which is also feebly represented in Yorkshire, and at its base in the former county is a deposit resembling the Stonesfield Slate, but of earlier date than that formation, known as the Collyweston Slate.

The Cornbrash, though a thin deposit, is singularly uniform in its character, being a brashy argillaceous limestone, though in places it is iron-stained.

Owing to the comparatively hard nature of many of the Lower Oolitic formations, they give rise as a rule to fairly high ground.

The Middle Oolites consist essentially of a clayey series at the base and a variable series at the summit. The clay series, known as the Oxford Clay, has in Wiltshire a hard, calcareous sandstone—the Kellaway or Kelaways Rock—at its base. The Oxford Clay itself is a fairly constant dark blue or slate-coloured clay, and the ground occupied by it is usually flat.

The Corallian beds of Yorkshire and of the south-western counties consist of oolites and other limestones partly formed of reef corals, with calcareous grit at the base and summit; they frequently occupy somewhat elevated ground. In Bedfordshire, Cambridgeshire, and Lincolnshire, however, with one insignificant exception near Cambridge, where calcareous rock is found, the representatives of the

Corallian beds are argillaceous, consisting of dark clays, and here is an uninterrupted accumulation of clay from the base of the Oxford series to the top of the Kimmeridge series, giving rise to the plain of the Great Ouse and the Fenland.

The Kimmeridge Clay is a bluish-grey laminated clay, brown when weathered, and often bituminous; it contains sandy layers in places.

The Portland beds are found chiefly in the extreme south of England, though clayey equivalents also occur in Yorkshire. In the Isle of Portland they are subdivided into Portland Stone above and Portland Sand beneath. The Stone is a white oolitic limestone, while the Sands are usually ferruginous.

The Purbeck beds consist of fresh-water and estuarine limestones, clays, and marls, with old surface soils intercalated with them.

The economic products of the Jurassic beds are varied. Building-stones are largely derived from the oolitic limestones, especially those of the Inferior Oolite, the Great Oolite, the Lincolnshire Limestone, and the Portland Stone, though other limestones, including those of the Lias, are also employed. Among the sandstones used for building are those of Midford Sand age, including the Ham Hill Stone, and the calcareous sands of the Estuarine series.

The utilisation of the Stonesfield and Collyweston slates for roofing purposes has been previously noted, and some of the fissile beds of the Forest Marble are used in the same way.

Many of the argillaceous beds of the Jurassic series are used for brick-making, including those of the Lias and of the Oxford Clay. The brick-making industry, which has become of late years so marked near Peterborough, is due to the nature of the Oxford Clay. Some of the calcareo-argillaceous rocks, especially those of the Lias, furnish hydraulic cement.

Iron ore is extensively worked in the Middle Lias beds of the Cleveland district of Yorkshire, and in the Estuarine series of Northamptonshire.

In addition to these products, most of the calcareous beds are burnt for lime, and many of the hard beds of the Jurassic system have been utilised for road-metal. The purer clays of the Fuller's Earth are used for fulling cloth.

With so variable a succession of rocks as is presented by the Jurassic system, the nature of the soil also presents many variations.

The Lias Clays give rise to pastures. The cattle reared on the Lower Lias clays of Gloucestershire furnish the milk for the double Gloucester cheese, and the milk which produces Cheddar cheese is obtained from cattle pastured on the lands of the Lower Lias and Trias of Somersetshire. The soil derived from the Middle Lias is rich, and in the south-western counties favours the growth of apples. The soil of the Midford Sands is usually of a fertile character. The Inferior Oolite gives rise to a reddish-brown brashy soil, the higher grounds being used for sheep-walks, but where the soil is deep it gives rise to good corn-growing country. The land occupied by the Fuller's Earth is usually covered by a heavy soil, which is not particularly fertile.

The soil of the Forest Marble is also usually poor, but capable of improvement by draining. The Cornbrash gives rise to a soil which is described by the name of the formation; it is, in the south-western counties at any rate, a brashy soil, good for the growth of corn. In Northamptonshire it is not so fertile. It possesses more phosphate of lime than do the underlying formations of the Jurassic system.

The Northamptonshire Sands form a rich soil, but the soil of the Upper Estuarine series of the Midlands is comparatively barren, and that of the Great Oolite Clay by no means fertile; while the rocks of the Estuarine series of Yorkshire, mainly owing to the elevation of the ground which is occupied by them, are chiefly marked by moorland.

The Lincolnshire Limestone is covered by a light, somewhat unproductive soil, though good barley is grown upon it in places.

The Oxford Clay land is difficult to cultivate, and requires draining. Most of it is under permanent pasture.

The Corallian rocks give rise to an arable soil of a sandy or brashy character, varying according to the nature of the underlying beds; the pasture is poor, and the soil unproductive in some localities. The soil of the argillaceous development is similar to that of the Oxford Clay.

The Kimmeridge Clay, again, yields an unproductive soil, most of the land being pasture land or meadow. Oaks grow well upon it, hence the name Oak-tree Clay given to it by William Smith. The Portland Stone gives rise to a poor, brashy soil.

The flora of the Jurassic rocks is characterised by

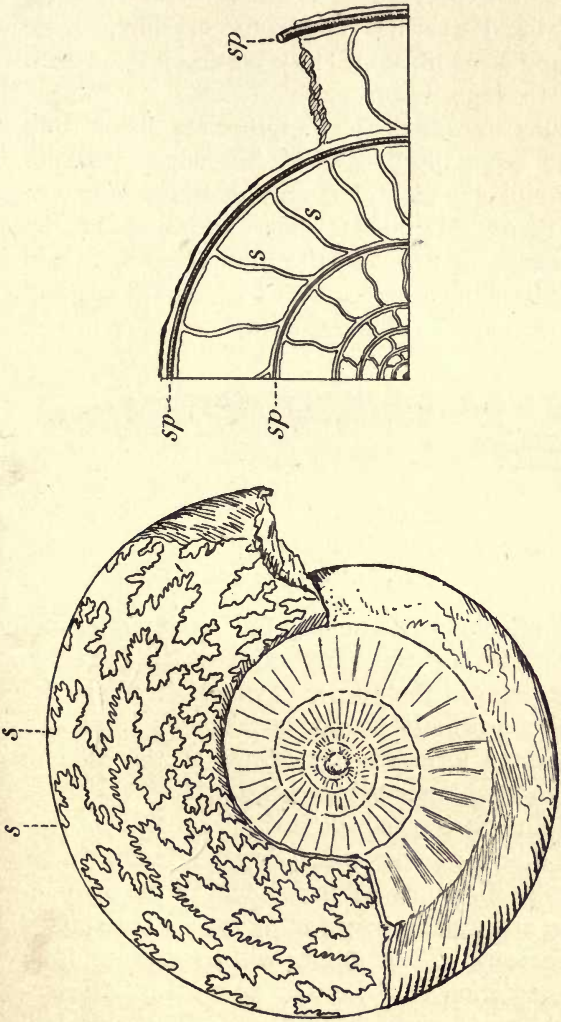


FIG. 98.

The left-hand figure shows an ammonite (*A. Parkinsoni*).
The shell is removed from the upper portion to show the sutures, *s s*.
The right-hand figure is a section through a portion of an ammonite of the same species.
s s=Septa. *s p*=Siphuncle.

the abundance of cycads. Plants are found abundantly in the Estuarine series of Yorkshire, where indeed they were of sufficiently luxuriant growth to give rise to deposits of coal.

The fauna shows a distinct approach to the existing fauna, and especially to that of Australia. Brachiopods are still abundant, but true molluscs now outnumber them. Mammals which appeared in the Triassic rocks are found in the Stonesfield slate and in the Purbeck beds, and a bird has been discovered in the Jurassic rocks of the Continent.

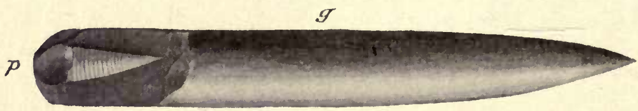


FIG. 99.

A BELEMNITE.

g=Guard. *p*=Phragmacone.

It is the Cephalopods among the invertebrates and the reptiles among the vertebrates which form the dominant notes in the Jurassic fauna. The Cephalopods which are most abundant are ammonites and belemnites, the former being related to the modern nautilus and the latter to the cuttle-fish.

The ammonite's shell differed from that of the goniatite described when discussing the Carboniferous rocks by the characters of the septa. In the ammonites these are usually very complex, and are spoken of as foliaceous. Their nature will be grasped from the representation of a Jurassic ammonite (*Ammonites Parkinsoni*) given in Fig. 98. The principal part of the belemnite which is preserved is a more or less conical calcareous body known as the guard, composed of concentric layers of carbonate of lime, usually of a brown colour. The upper part of this guard is marked by a conical cavity, in which was inserted a chambered tube with simple septa and a marginal siphuncle.

The structure of those hard parts of a belemnite which are commonly preserved is exhibited in Fig. 99.

Study of the following Jurassic fossils will be found useful :—

Paludina . . .	Purbeck Beds.
Trigonia gibbosa . .	Portland Beds.
Ostrea deltoidea . .	Kimmeridge Clay.
Exogyra virgula . .	Kimmeridge Clay.
Ammonites biplex . .	Kimmeridge Clay.
Thamnastræa arachnoides .	Corallian.
Cidaris florigemma . .	Corallian.
Gryphæa dilatata . .	Oxford Clay.
Ammonites cordatus . .	Oxford Clay.
Belemnites Oweni . .	Oxford Clay.
Avicula echinata . .	Cornbrash.
Apiocrinus Parkinsoni .	Bradford Clay.
Terebratula fimbria . .	Great Oolite.
Ostrea acuminata . .	Fuller's Earth.
Ammonites Murchisoni .	Inferior Oolite.
Pentacrinus briareus . .	Lias.
Hippopodium ponderosum	Lias.
Gryphæa arcuata (= incurva)	Lias.
Ammonites communis .	Lias.
Ichthyosaurus, bones of .	Lias.

THE CRETACEOUS SYSTEM

The Cretaceous rocks of England are traceable from Flamborough Head in Yorkshire, through Lincolnshire, East Anglia, Beds, Herts, Bucks, Oxfordshire, and Wilts, to the sea in Dorsetshire. From Wiltshire an anticlinal of Cretaceous rocks extends eastward through Hampshire, Surrey, and Sussex to Kent.

The system receives its name because it contains the well-known chalk deposits, but in addition to these there is a great variety of deposits included in this system. The chalk occupies the largest area in England which is covered by any one deposit.

The Cretaceous beds of England are classified as follows:—

- Cretaceous
  - Upper
    - Chalk
      - Upper.
      - Middle.
      - Lower.
    - Upper Greensand and Gault.
  - Lower
    - Lower Greensand, Wealden Beds, Hastings Sands = Speeton Clay (approximately).

Cretaceous beds are also found in some of the western isles of Scotland and in the north-east of Ireland in Antrim.

The Lower Cretaceous rocks are most extensively developed in the Wealden district of the south-east of England, and as the Upper Cretaceous rocks are well seen on either side of this district, a section across the district from north to south is here inserted to give an idea of the mode of occurrence of the rocks of this system in the southern area (Fig. 100).

In the Weald area the Hastings Sands form the lowest deposits; they are succeeded by the Weald Clay. Sands and clay are alike of fresh-water origin. The sands consist of yellow and white sandstones, with some clays and deposits of iron-ore. The Weald Clay is blue, but weathers to a brown colour, and contains beds of fresh-water limestone, sandstone, and iron ore.

The Lower Greensand is a very variable group of deposits. It receives its name from the frequent presence of grains of glauconite, which give the sands a greenish hue. In addition to this, non-glauconitic sands, clays, limestones, and cherts are found in it. The fossils show that the deposits are marine. A development of Lower Cretaceous beds somewhat similar to that described above is also found in the Isle of Wight.

Along the main line of outcrop of the Cretaceous beds in the home counties, and as far as North

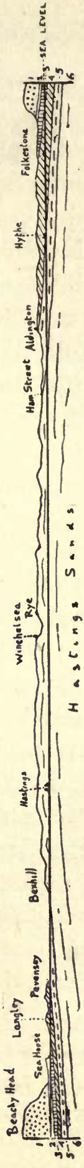


FIG. 100.

SECTION ACROSS THE WEALD (after De la Beche).

1. Chalk. 2. Upper Greensand. 3. Gault. 4. Lower Greensand. 5. Weald Clay. 6. Hastings Sands.

Norfolk, the strata rest unconformably upon the Jurassic rocks. The fresh-water beds of the Weald area are not represented, and usually only the very highest members of the Lower Greensand are found. They usually consist of shallow water, iron-stained sands, and pebble beds, which have yielded phosphatic nodules at Brickhill (Bucks), Potton (Beds), and Upware (Cambs).

In Norfolk these beds are known as Carstone. Passing into Lincolnshire, the lower beds of the Lower Cretaceous rocks again appear in the guise of marine sediments. In that county they are largely sandstones, with some deposits of iron ore, and form the Spilsby Sandstone in part and the Tealby beds. There appears to be a perfect conformity between Cretaceous and Jurassic rocks in this county, and also in Yorkshire, where the Lower Cretaceous rocks exist as a blue marine clay, the Speeton Clay, the lowest portion of which is, however, referred to the Jurassic system.

The Gault and Upper Greensand are treated together in the basal division of the Upper Cretaceous rocks, for there is little doubt that parts of the Upper Greensand represent the Gault, and that in some localities in the south the whole of the Gault is replaced by beds having the lithological characters of a Greensand.

The Gault is a stiff blue clay, often glauconitic, and frequently containing phosphatic nodules, as in Buckinghamshire. It is typically developed in the south-eastern counties, and also along the main line of outcrop in a northerly direction to the neighbourhood of King's Lynn, in Norfolk. Towards the south-west the Greensand facies replaces the clay, and there is a discordance between the Upper Cretaceous rocks and lower formations, so that in Dorset and Devon the Upper Cretaceous rocks rest respectively on Oolites, Lias, Trias, and even on Palæozoic rocks.

In the north of Norfolk the clayey Gault passes by degrees into a thin deposit known as red chalk, which is found at Hunstanton, and through Lincolnshire and Yorkshire to the coast at Speeton. It is a red calcareous rock, often containing clay in considerable amount.

The Chalk is a white, earthy limestone, composed largely of the tests of foraminifera, mingled with minute calcareous plants, and with complete or fragmentary tests of higher organisms. It varies considerably in its characters when examined in vertical sequence, and also when traced laterally.

The division into Lower, Middle, and Upper Chalk is primarily based on lithological characters, the Lower Chalk being without flints and containing much clay towards the base, when the deposit is termed chalk marl, the Middle Chalk having a few scattered flints, and the Upper Chalk many flints in nodules parallel to the planes of bedding, and also in vertical joints running along the joint-planes.

In Cambridgeshire the chalk rests unconformably upon the Lower Gault, and the basal pebbly bed of the chalk is a glauconitic chalk marl, with abundance of phosphatic nodules, partly derived from the denuded Upper Gault and partly formed *in situ.*

Phosphatic deposits have also been found at

Taplow, where certain lower beds in the Upper Chalk contain numerous small brown grains of phosphate of lime. The richer portions of these beds yield over thirty per cent. of the phosphate.

In Yorkshire the chalk is much harder than in the southern counties, and the same is the case in the north-east of Ireland.

The Hastings Sands of the Weald area form high ground, while the Weald Clay gives rise to plain. The Lower Greensand often rises into a high escarpment, and the Gault forms another plain. When the Upper Greensand is well developed it may give rise to yet another escarpment, separated from the main chalk escarpment by comparatively low ground occupied by chalk marl. The chalk escarpment is often double, the less prominent scarp being determined by the Lower Chalk and the more prominent one by the Upper Chalk.

With regard to the economic products of the Cretaceous rocks, we find, in addition to the iron ores and phosphatic deposits already mentioned, numerous substances of utility in Lower and Upper Cretaceous rocks.

The Wealden beds furnish some building-stones (Horsham stone, etc.), and some of the Paludina limestones are used for ornamental "marbles."

Many of the Lower Greensand deposits furnish good building-stone, and Fuller's Earth occurs near Reigate.

The Speeton Clay is made into bricks, and yields septarian nodules for hydraulic cement.

The Gault is largely worked for bricks in Cambridgeshire, Bedfordshire, and Kent.

The Upper Greensand is in places quarried for building-stones, and yields hearthstones in Kent and Surrey. Whetstones are made from siliceous beds of this age in Dorsetshire and Devonshire.

The chalk is largely burnt for lime in very many places.

Some of the beds are used for building purposes, as, for example, the Beer Stone in Devonshire. A hard bed in Cambridgeshire and the neighbouring counties known as the Totternhoe Stone has been used in the interiors of churches. Flints from the Upper Chalk are also used for buildings in Norfolk and elsewhere; they are also utilised for road-metal and in the manufacture of glass, china, and porcelain.

The soils of the Cretaceous rocks, like those of the Jurassic beds, naturally present considerable variations. The Hastings Sands give rise to light, sandy soil, though a better quality of soil exists over these beds in the district to the south-east of Tunbridge Wells, where hops are grown.

The soil furnished by the Weald Clay is a stiff, clayey soil, usually poor, except when covered by superficial deposits of gravel. Hops are also grown upon the soil overlying the Weald Clay.

The lowest division of the Lower Greensand, known as the Atherfield Clay, may be looked upon as a continuation of the Weald Clay so far as its soil is concerned.

The other divisions are sandy in the Wealden district, and usually furnish light soils, though these vary greatly in their degree of productivity. The uppermost division (the Hythe beds) furnishes the most fertile soil, and nearly all of the hop gardens of the Maidstone district are situated upon it.

The development of Lower Cretaceous rocks, from Oxfordshire to Norfolk, is responsible for soil of great sterility, on which little can be grown save Scotch firs, but the sand of these rocks when washed into the alluvial deposits of the valleys causes the soil to be extremely productive.

The soil of the Gault is usually unproductive, though well fitted for pasture land. Owing to the clayey character of the soil and the prevailing flatness of the land, the ground is often marshy.

The Upper Greensand supplies soil of great fertility. Hops grow well on it, and its crops of wheat are excellent.

The chalk is characterised as a rock by its short, sweet herbage, well adapted for sheep-grazing, where the rock rises into downs and wolds. The lower ground occupied by chalk, and especially by the argillaceous chalk marl, is largely arable land, and much of the chalk land which is under the plough is really covered by glacial drifts or alluvia. Beech trees grow upon the chalk in great profusion in many places.

Some parts of the Upper Chalk, especially where glacial action has not modified the surface, are covered by an accumulation of material which is the insoluble residue of the chalk removed by percolating water. This residue is known as clay-with-flints, and often consists of little else than a mass of broken flints. Little will grow on it, though in places it has been made to yield good root crops.

The fauna of the Cretaceous rocks resembles that of the Jurassic rocks in many respects. Belemnites and ammonites are abundant, and extinct groups of reptiles are also strongly represented.

The chalk contains a considerable number of the group of fossils known as echinids, or popularly as sea-urchins, one of which (*Ananchytes ovatus*) is

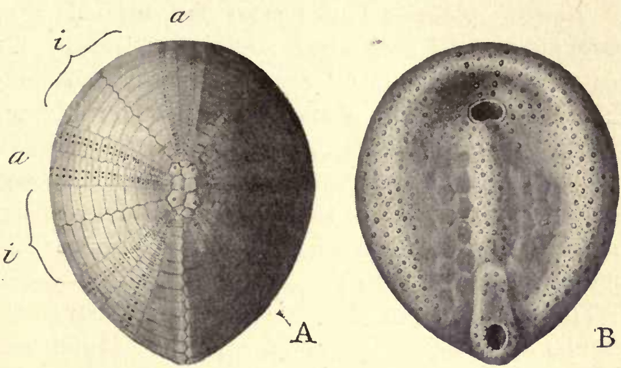


FIG. 101.

Ananchytes ovatus.

A = Upper, B = Lower surface.
a = Ambulacral } areas.
i = Interambulacral }
The oral and anal apertures are seen in B.

shown in Fig. 101, in order to illustrate the characters of these organisms.

The tests of these creatures, though actually exhibiting bilateral symmetry, have an apparent radial symmetry. The test is usually globular or heart-shaped. It consists of two parts—an assemblage of small plates on the summit, known as the apical disc, and the rest known as the corona. The structure of the apical disc is not often easily made out; it usually consists of a ring of ten plates, five inner and five outer ones.

The corona is usually formed of twenty rows of plates, extending from the summit of the test towards the opposite pole. These rows are arranged in pairs, a row of pairs of broad plates alternating with one of narrow plates. The former are termed interambulacral, and the latter ambulacral areas. The plates of the ambulacral areas are perforated. The junction of the plates in the centre of each row forms a zigzag line, as shown in the figure. The plates are furnished with elevated tubercles, to which were attached spines, though the spines are usually absent in the case of the fossil tests, being, however, frequently found separate.

The echinids are divided into two groups—the regular and irregular echinids. All the echinid tests possess two orifices, an oral and an anal opening. In the regular urchins the anal aperture is always on the summit of the test, within the apical disc, and the oral aperture at the opposite pole. The tubercles on the interambulacral plates especially are large and often perforated. The whole test usually approaches very closely to radial symmetry. The genus *Cidaris*, whose remains are somewhat rarely found in the chalk, belongs to the regular group.

In the irregular group the test usually approaches radial symmetry in a much less marked degree. The anus is always outside the apical disc, while the mouth may be central or excentric. The tubercles of these urchins are usually minute.

Fig. 101 represents the test of an irregular urchin.

The following is a list of some of the Cretaceous fossils:—

Spondylus spinosus	. .	Chalk.
Ananchytes ovatus	. .	
Holaster subglobosus	.	
Belemnitella mucronata	.	
Terebratula biplicata	.	Gault.
Ammonites rostratus	.	
Exogyra sinuata	. .	Lower Greensand.
Gervillea anceps	. .	
Unio valdensis	. .	Wealden.
Lepidotus Mantelli	. .	

CHAPTER XX

THE TERTIARY ROCKS

IF we leave the Quaternary deposits out of account, we shall find that the Tertiary rocks of Britain are developed in three principal areas, viz. the London Basin and East Anglia, the Hampshire Basin, and the north-east of Ireland and western isles of Scotland.

The Lower Tertiary rocks of the London and Hampshire basins are separated by the Wealden anticline, and there is no doubt that before the folding occurred Tertiary beds once covered the Cretaceous rocks of the intermediate country. These Tertiary rocks rest upon the chalk with an unconformable junction, which has been emphasised owing to underground solution of the surface of the chalk after the deposition of the Tertiary strata.

THE EOCENE STRATA

The beds of the Eocene strata are chiefly incoherent sands and clays, with some marls and thin limestones, the latter being confined to the Hampshire Basin. Some writers separate the higher beds of the Hampshire Basin from the Eocene, and place them in a separate division, the Oligocene, but it will be convenient if we retain them in the Eocene division. The beds may be classified as follows :—

Fluviomarine beds of the Hampshire Basin.
Upper Bagshot Sands.
Barton Clay.
Bracklesham Beds.
Lower Bagshot Sands.
London Clay.
Lower London Tertiaries.

In the London Basin the Lower London Tertiary beds form a narrow strip around the basin. They are therefore of no great importance to us. They consist of variable series of pebble beds, sands, clays, and marls.

The most extensive deposit of the London Basin is the London Clay. It is a stiff brown or bluish clay of marine origin, though doubtless deposited at the mouth of a large river.

The higher Eocene beds of the London Basin are usually spoken of as the Bagshot beds, for the Barton and Bracklesham type of deposit is not found, and the series consists essentially of yellow sands with occasional clays. These Bagshot beds cap the hills of the neighbourhood of Brentwood, and also those of Harrow, Highgate, Hampstead, and others near London, but the most extensive development is further west in north-west Surrey and Berkshire.

In the Hampshire Basin, which is continued in the north part of the Isle of Wight, the Lower London Tertiary beds are poorly developed. The London Clay is found over a considerable area in Hampshire and

Sussex, though it is sometimes represented by sandstones, as at Bognor. The Bracklesham and Barton beds, which are intercalated between the Lower and Upper Bagshot Sands of the basin, are clays with numerous fossils. A patch of beds of Lower Bagshot age occurs on the flanks of Dartmoor. These beds are known as the Bovey Tracy beds, and contain lignites.

The Fluviomarine series is found in the north of the Isle of Wight and in the New Forest. As the name indicates, the beds are partly of marine and partly of fresh-water origin.

In the Scotch and Irish area the Tertiary rocks are of very different character, consisting of volcanic rocks with intercalated lignites, sands, and clays. The volcanic rocks are sometimes fragmental, but consist essentially of widespread flows of basaltic lava, which are familiar to all as occurring at the Giant's Causeway, in the Isle of Staffa, and elsewhere.

Among the economic products of the Tertiary beds we may mention clay for the formation of bricks. The London Clay is well adapted to this purpose, and among other clays so used are those of the Lower London Tertiaries near Reading. The clays of the Lower Bagshot beds of the Hampshire Basin furnish potter's clay and pipe-clay.

The marls of one of the lowest divisions of the Fluviomarine beds of Hampshire, viz. the Lower Headon beds, have been utilised for marling the land.

The soil supplied by the London Clay is usually stiff and sometimes loamy. It makes good pasture land, and when marled yields good corn crops. Timber grows profusely on this soil in many places.

The Bagshot Sands give rise to a very unproductive soil, largely occupied by heaths and fir plantations.

As the Fluviomarine beds are extremely variable, a great variety of soil arises from their superficial disintegration.

The fauna and flora of the Lower Tertiary strata resemble that of the present day, most of the genera being now living, though the greater number of the species are extinct. As the deposits are chiefly of shallow-water origin, the fauna is essentially molluscan, gasteropods and bivalve lamellibranch shells predominating. It is hardly necessary to describe the structure of these shells, as the student may easily see the principal structures of a gasteropod by examining specimens of the snail, periwinkle, and whelk, and those of the bivalves by inspection of oyster, cockle, and mussel.

The nature of the aperture, and the angle of the apex of the gasteropod, are important in distinguishing genera, and for the same purpose the internal structures of the bivalve shell, as the nature of the hinge-teeth, must be considered.

The following are some of the fossils of the Eocene beds :—

Planorbis euomphalus .	Fluviomarine Beds.
Limnæa longiscata .	
Crassatella sulcata .	Barton Beds.
Murex asper . .	

Nummulites . . Conus deperditus . .	Bracklesham Beds.
Pectunculus brevirostris Voluta nodosa . .	London Clay.
Cyrena cuneiformis . Melania inquinata .	Lower London Tertiary Beds.

Fishes, reptiles, and mammals are also found in many of the strata both in the London and Hampshire basins.

THE MIOCENE PERIOD

No beds of this age are known in the British Isles. This was a period of great earth-movement in our area, when the Secondary and Lower Tertiary beds received their present inclination, and the sea areas were converted into land. The British Isles as land may be said to have originated in Miocene times, and as the result of the uplift much denudation also occurred. Other changes have taken place since, but little of our island has been submerged for any length of time, and accordingly the Upper Tertiary marine strata have a very limited distribution.

THE PLIOCENE BEDS

The principal Pliocene strata are found in East Anglia, mainly in Norfolk and Suffolk. They are thin, shelly deposits, occurring in scattered patches, usually spoken of as 'crags.' For our purpose a division into Upper Crags and Lower Crags will be sufficient.

The Lower Crag or Coralline Crag consists of calcareous shelly sands with a considerable proportion of carbonate of lime, found in Suffolk. At its base in places is a bed containing nodules of phosphate of lime.

Of the Upper Crags the oldest member, the Red Crag, occurs in Suffolk and Essex. It is a red quartzose sand, sometimes shelly, but much less calcareous than the Coralline Crag. An important bed of phosphate nodules is found at its base.

In Norfolk the Upper Crags are found near Norwich and near the coast. They consist chiefly of sands with shelly patches, though at Cromer carbonaceous deposits are found forming part of the Cromer Forest series.

The beds are so variable, and their lateral spread so limited, that any description of the soils produced by them would be of no general value.

The shelly clays have been extensively used for marling the land.

Among the Pliocene fossils we may note:—

Littorina littorea and other common living molluscs	Norwich Crag.
Fusus (Chrysodomus) contrarius (a reversed gasteropod)	Red Crag.
Terebratula grandis	Coralline Crag.
Astarte Omalii	

THE QUATERNARY ACCUMULATIONS

The Quaternary beds may be classified as (i) glacial and (ii) post-glacial.

The glacial accumulations are found north of a line drawn from the mouth of the Thames to the Bristol Channel. In this area their distribution is only partial. They often form thick coverings over the low ground, though they have been frequently cut through by the rivers, and are absent from the valley sides and floors. In upland regions, on the contrary, they are most developed in the lower parts of the valleys, while the hilltops and upper slopes are bare of glacial materials.

The nature of the deposits also varies greatly. Boulder-clays consisting of stiff clays with glaciated boulders predominate, but considerable tracts of sandy material also occur. The distribution of the clays and sands can only be found by careful study of each area, though it is now indicated upon the drift-maps published by the Government Geological Survey.

The glacial deposits, being so frequently formed of clay, usually give rise to a stiff soil. As this soil has been derived from so many materials, it differs greatly as regards fertility. In the eastern counties of England the greater part of the boulder-clay belongs to the accumulation known as great chalky boulder-clay, as it has much chalky material associated with it, and also contains boulders of this rock. It is often very fertile, and yields good crops of wheat and barley. In the hill districts, however, a great deal of the ground occupied by boulder-clay is waste land largely of a rushy nature.

Of post-glacial deposits, the more important are the various alluvia, rainwash, and blown sands. The nature of these deposits has already been considered in the earlier portion of this work, and need not be further discussed. There is one post-glacial accumulation, however, which requires further notice than has been given to it in the preceding pages, namely, the peat.

It has already been seen that there is every gradation, from soils containing little vegetable matter to those in which the vegetable matter occurs in larger percentage than that composed of mineral particles. The peats of temperate and higher latitudes contain this large percentage of humus, the inorganic ash being sometimes only two or three per cent. of the whole substance, though it is usually greater than this. Peat also contains a considerable quantity of water. The upper parts of peat accumulations have undergone less change than the lower parts, and retain the structures of their component vegetation to a greater extent.

Peat-growth occurs in cool or cold, moist climates, where there is a lack of natural drainage, owing to impervious rock beneath, and to slight slope of ground, as in the English fenland, or to obstruction of drainage by some obstacle, as in mountain peats. Some of the fenland peats have been claimed to be due to forest growth, but Mr. Skertchley has shown that the periods of forest growth were marked by cessation of peat-formation, and that the peats of the fenland, like those of hilly regions, are due to swamp vegetation. The fenland peat is largely composed of the remains of aquatic herbaceous plants; that of the Irish bogs contains much Sphagnum, and many of the hill-peats contain heath, sweet-gale, and other plants in abundance.

CHAPTER XXI

WATER-SUPPLY

OF the rain which falls upon the surface of the ground some flows on this surface to the rivers and is carried to the sea, while the rest soaks into the ground.[1] The amount which is taken up by the ground depends, other things being equal, upon the permeability of the materials which form the upper part of the land. We thus speak of rocks as being *pervious* or *impervious*, though these terms are used relatively, no rock being absolutely impervious to the passage of water. Clays are the principal rocks which are relatively impervious, while sands and limestones are relatively pervious.

Should the ground be practically flat, the underlying materials must eventually become *saturated*, and the surplus water will then gradually soak away seaward or be restored to the atmosphere by evaporation ; but when the ground is uneven, the rain which has been absorbed at a higher level may appear at the earth's surface again at a lower level in the form of *springs*.

The conditions which are most favourable for the existence of springs may be best illustrated by means of a diagram (Fig. 102), it being, of course, understood that the rainfall of the district is sufficient to furnish a supply of water.

[1] Except that which is evaporated.

The figure represents a cross-section through a hill of which the upper part is composed of sandstone indicated by the dotted portion, while the lower portion marked by the continuous lines is formed of clay. The strata are drawn with a slight dip towards the east, though this is not necessary for the production of springs; such a dip does, however, produce certain noteworthy occurrences, which will be discussed immediately.

If we suppose that the hill at the outset contained no water, and that after rainfall water was absorbed

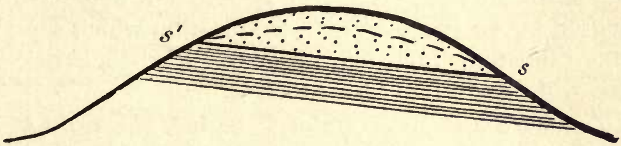


FIG. 102.

SECTION SHOWING FORMATION OF SPRINGS.

by the sandstone, this water would gradually work its way down the sandstone along the interstices between the component grains as well as through fissures, such as joints. When it came to the impervious clay, which it could not penetrate, it would proceed along the line of junction between sand and clay, and would, with the conditions represented in the diagram, flow, in the first place, downward in an easterly direction to *s*, where it would come to the surface. A general soaking of water along the line of outcrop of the plane of stratification separating the sandstone from the clay might then take place on the eastern slope of the hill, but some cause conducive to easy escape of the water, such as a prominent joint-plane running through the sandstone down to its junction with the clay, would probably account for the issue of water in greater quantities at certain points along the outcrop of the eastern slope, giving rise to *springs* at intervals. Such a spring, then, may be supposed to exist at *s*.

Owing to capillarity and friction the water will take some time to soak through the sandstone and issue at a lower level, and accordingly if more rain should fall before the products of the last fall have escaped, the level of the water will rise to an appreciable degree above the plane of stratification which separates sandstone from clay, and the sandstone below this will be saturated with water.

As more and more water is added, the *saturated portion* of rock will become more and more extensive, and at last the upper surface of this saturated rock will reach the ground at *s′*, where springs will then be formed.

The upper surface of this saturated portion will not be a plane surface parallel with the plane of stratification, but a curved surface rising from *s s′* inward, for the water escapes more rapidly from the parts adjoining the outflow than from parts which are more remote from it. The dotted line in the figure shows the upper limit of such a *curve of saturation*, or *water-table*, as it is sometimes termed. This curved surface will fluctuate with the seasons, rising in wet seasons and sinking in times of drought; at the latter times the springs along *s′* may cease to flow, but will renew their outflow when a wet period follows.

Intermittent springs are often found, especially in chalk districts, at a somewhat higher level on a hillside than that of the outcrop of the junction of the impervious and pervious beds. These springs run in wet weather owing to the rise of the curve of saturation until it reaches some weak spot at a higher elevation than that of the normal springs along the junction. They often flow in winter only; hence the name Winterbourne, which is applied to many villages which grow up around springs of this character.

Should the water from a pervious deposit of limited area be extensively drawn upon by sinking wells, it is evident that unless the supply of rain is sufficient to restore the water which is thus abstracted, the saturation surface will be permanently lowered and the available water-supply be eventually exhausted. It is also evident that the surface of water in such wells will coincide with the point at which the well cuts the curve of saturation, and that it must be raised to the surface by artificial means.

In certain conditions, however, a supply of water may be obtained which comes to the surface and in some cases actually rises above it in the form of a fountain. When these conditions exist, wells are sunk to obtain the water, and these wells are termed *artesian* wells, from the province of Artois, in France, where they have long been used for water-supply.

Fig. 103 represents the conditions which allow of the successful boring of artesian wells. The pervious beds *ch*, which may be taken to represent chalk, lie between two groups of impervious clays *c, c.* The chalk rises into hills when it crops out at the surface, while a valley *v* is excavated in the upper clay, but does not cut down to its base. The rain which falls on the chalk hills is absorbed, and gradually works to the lower part of the chalk at the bottom of the geological basin represented in the diagram. This water cannot escape, and if the rainfall be sufficient, the surface of saturation will continue to rise until

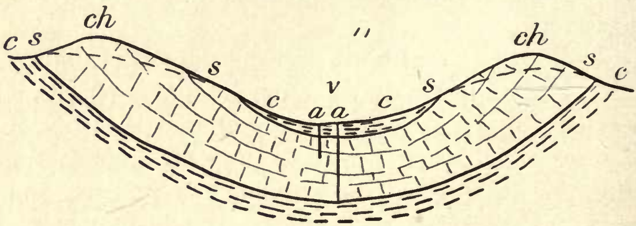


FIG. 103.

SECTION SHOWING CONDITIONS FAVOURABLE TO SINKING ARTESIAN WELLS.

c = Clays. *ch* = Chalk. *v* = Valley. *s s* = Saturation-lines. *a a* = Artesian wells.

it coincides with the junction of the chalk and upper clay, where those strata reach the ground, and forms curves in the chalk below the tract where this rock crops out at the surface, as shown by the dotted lines in the figure. At *s s* . . . ordinary surface springs will be formed, but the water cannot rise in the valley, owing to the impervious upper clay. If this be tapped by a well, however, the water, owing to hydrostatic pressure, will rise in the well and may spout up at the surface to a height a little below that of the curve of saturation, where the surface springs exist: *a*, *a* in the figure represent two artesian wells of this type.

The Thames Valley at London is in an area of which the geological structure is similar to that above described. Below the river gravels of the Thames is the great mass of London Clay. Beneath it is chalk, and at the bottom of the chalk are other clays, the chalk marl, and the Gault. The water which falls on the hills of Hertfordshire and Essex to the north, and on the North Downs to the south of the Thames Valley, sinks into the chalk, which, besides being porous, is penetrated by numerous fissures, and when the London Clay is pierced the water rises. Owing to the great consumption of water in London, the saturation curve is being gradually lowered, and this source of supply must be eventually exhausted. The question of the water-supply for London is, indeed, already an acute one.

Fig. 104 represents other conditions suitable for the sinking of artesian wells, where, instead of a basin, strata are found to be inclined in one direction, the pervious strata as before being situated between two groups of impervious strata; but the pervious strata are cut off underground by a fault, which has caused them to abut against impervious strata. The conditions which are favourable for the existence of natural springs are also often suited for the occurrence of landslips. In Fig. 102 landslips will be apt to occur on the side of the hill represented to the right of the figure, where the strata are dipping towards the surface at the outcrop, and not on the left hand, where they are inclined away from the surface. The tendency to landslips is increased by addition of water, partly because the water lubricates the surface of the impervious strata, thus diminishing the friction; partly, also, because the addition of water to the permeable strata adds to their weight. Landslips accordingly are especially

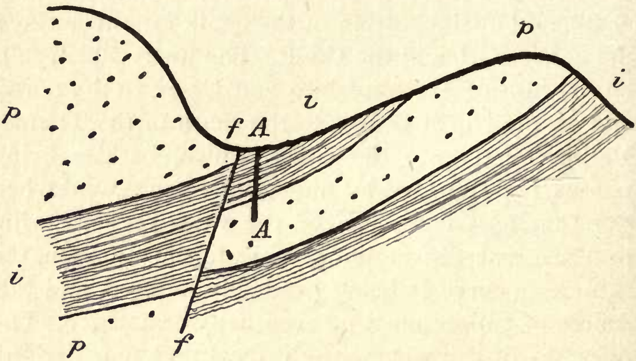


FIG. 104.

SECTION OF FAULTED STRATA SHOWING CONDITIONS FAVOURABLE FOR ARTESIAN WELL.

p = Pervious } strata.
i = Impervious }
f = Fault. *A A* = Shaft of well.

apt to take place after a prolonged spell of wet weather. If the slope of the ground be artificially increased where the conditions favourable to landslips naturally exist, the tendency to slipping will also be increased. In making road-cuttings, therefore, if it is equally convenient to take the road on either side of a hill such as that represented in Fig. 102, the road-cutting should be made on the west side of the hill, and not on the east side.

The water-supply of our own country is naturally yielded, to a large extent, by the beds of those geological systems which contain a considerable amount of pervious rock, such as sandstone and limestone. The water furnished by sandstone is usually soft, that yielded by limestone hard, though some of the sandstones which contain sulphate of lime yield a permanently hard water, which cannot be rendered soft by boiling, whereas the water of limestone beds is temporarily hard, as the soluble bicarbonate of lime is converted into the insoluble carbonate when the water is boiled.

We may now proceed to consider the water-bearing capacity of the different strata of our island in the order of their antiquity.

The Lower Palæozoic strata and the igneous rocks which are so frequently associated with them are to a considerable degree impervious, and the same may be said of other igneous rocks. Where sandstones occur in the Lower Palæozoic strata, a supply of water may be obtained by well-sinking, but as these strata are often highly indurated, and the physical conditions of the regions occupied by these rocks are often favourable to the formation of natural and artificial reservoirs, the water-supply is usually obtained from the surface. Indeed, as the supply derived from beneath the ground in districts occupied by newer rocks becomes exhausted, the large towns situated upon these rocks are often compelled to obtain their water from distant sources; thus Manchester is supplied from Lake Thirlmere in Cumberland, Liverpool from the artificial Lake Vyrnwy in North Wales, and

Birmingham from the Rhayader Valley; and other towns are also being driven to obtain their supply in a similar manner.

In the Devonian system the rocks of Old Red Sandstone type furnish an abundant water-supply.

Many of the Carboniferous beds are very pervious, and furnish abundant water. The rain is stored up in the fissures of the Mountain Limestone, and abundant springs of hard water issue from this formation. The sandstones and gritstones of the millstone grit and coal-measures also furnish an abundant water-supply to many towns of those districts which are situated upon them, though the larger towns of these districts have also been compelled to resort to reservoirs for the storage of water.

The rocks of New Red Sandstone age, especially those belonging to the Triassic system, furnish an excellent supply of water. The Bunter Sandstone is very pervious, and the same is the case with the Keuper Sandstone, and also with a group of sandstones intercalated with the Keuper marls, and known as Waterstones, though the marls themselves are essentially impervious. The gypsum in the Keuper Sandstones renders the water especially adapted for brewing purposes; hence the important breweries of Burton-on-Trent.

The calcareous and arenaceous members of the Jurassic deposits, as some of the Lower Oolites, and the Corallian rocks furnish much water in many localities, though the great clays, as the Lias, Oxford, and Kimmeridge clays, are largely impervious.

The Cretaceous beds contain many porous strata, of which the principal are the Lower Greensand and the Chalk, and to a less degree the Upper Greensand. It has already been stated that the value of the chalk as a water-bearing deposit is due, not merely to its porosity, but to the number of fissures which exist in it. When these fissures are tapped, a specially copious supply of water is furnished.

The sandy Tertiary beds also supply water. In the South of England the Bagshot Sands are locally important as a source of water-supply.

The variation in the characters of the glacial deposits is so great, and the changes take place so irregularly, that no definite statement can be made as to the likelihood of water being found in any particular place, for sandy beds may occur below boulder-clays in many places without giving signs of their presence upon the surface.

The alluvial gravels have been largely used for local water-supply in former times. As the towns stand on these pervious rocks without the existence of any impervious layer above, the water of these gravels is frequently contaminated by sewage, and is therefore unfit for drinking purposes; and indeed this is the case to some extent with deeper-seated sources of water-supply, where large towns are situated upon the pervious strata, for it has been proved that sewage filters through these strata for long distances from the spot where it has entered the ground.

The soil itself is a more or less porous accumulation, and may be charged with water, which is, for agricultural purposes, in excess, or is, on the contrary, insufficient. In the latter case irrigation must be resorted to, though this is seldom adopted in our country, except in the case of water meadows, where the water is introduced from a river through channels and carried back into the river at a lower level.

When there is excess of moisture the excess must be removed. This excess may be due to two causes, viz. to water rising from underground, and to rain-water being unable to penetrate the ground owing to the existence of impervious material below.

The first case often occurs along the line of junction of an overlying pervious and underlying impervious stratum, or set of strata, where the conditions are favourable for the formation of springs. These springs, as already stated, rise at points along the outcrop, where the conditions are favourable to a copious discharge. In the intervals the water soaks slowly through the soil and renders it marshy. In such cases wells must be sunk into the pervious rock, and the water which rises in these wells must be carried off by means of drains.

When the soil is too wet, owing to the existence of impervious material beneath it, the soil must be drained. The soil, like other pervious materials, has an upper limit of saturation, which may reach the surface. By drainage this saturation plane is lowered and the surface thus rendered drier.

CHAPTER XXII

MATERIALS DERIVED FROM ROCKS WHICH ARE USED FOR IMPROVING SOILS

OF the materials which the rocks of the earth's crust yield, some are useful for producing changes in the physical conditions of the soil, while others directly furnish food for the plants.

It would be out of place to describe at great length in the present work the mode of occurrence of the various products which have been or are utilised for improving the soil, for such knowledge would be of little practical utility. It will not be amiss, however, to give a short account of the conditions under which some of these products occur, especially those of the British Isles.

We have seen that sand, clay, and lime are the principal inorganic constituents of the soil, and a soil which contains a deficiency of these constituents, for any particular purpose may, of course, be enriched by its addition. It is often found advisable to add lime or clay to natural soils. Lime is derived from the *calcination* of natural limestones, which causes the expulsion of the carbon dioxide (carbonic acid gas). Any limestone may be utilised for this purpose if sufficiently pure. The principal limestones which are so employed in Britain are those of the Devonian, Carboniferous, Jurassic, and Cretaceous systems.

Marling is also for the purpose of adding to the original constituents of the soil. It has already been pointed out that marl, in the strict sense of the term, is a mixture of clay and lime, and thus both these substances are added to the soil when this marl is applied. Marls are developed in the Jurassic and Cretaceous rocks of Britain, and to some extent among the Pleistocene "Crags" of East Anglia. The frequent occurrence of shell-marls at the bases of peat bogs marking the sites of former lakes has already been described.

The term marling is sometimes applied to the addition of clay devoid of any intermixture of lime. Light soils are improved by marling of this character, as, for example, the soils above the Triassic and Lower Cretaceous sandstones.

On a large scale clay may be added in lowland regions by a process of *warping*. Natural warping takes place along the lower course of the Nile, and artificial warping is extensively conducted in the north-west of Lincolnshire. The area is divided into tracts which are flooded by water conveyed from the rivers. The process takes about three years to complete, the water being conveyed to each tract twice a day for some ten days in each of the summer months. The silt is deposited from the water, and forms a rich soil in the place of the poor peat which it covers.

Among other natural products of the rocks which improve the soils may be mentioned various nitrates, sulphates, chlorides, and phosphates of the alkalies or alkaline earths. Some of these must undergo various treatments after their extraction before they can be used.

Nitrate of soda is found as a superficial accumulation in the desert tracts of several regions, especially of Peru and Chili.

Chloride of sodium (common salt) is found in the rocks of many regions which were deposited during periods of great evaporation of inland lakes. Among the best known of these are those associated with the Keuper marls of Cheshire and the Pliocene deposits of Poland.

Gypsum (sulphate of lime) is often an accompaniment of rock-salt. It is found in many places in England among the Permian and Triassic rocks.

Kainite (chloride of potassium, with sulphate of magnesium and water), which has been extensively utilised as a manure, occurs with deposits of rock-salt and gypsum in the rocks of Triassic age at Stassfurt, in Germany. Like rock-salt and gypsum, it occurs in the form of beds interstratified with deposits of mechanical origin, and with other chemical precipitates of varying composition.

Lastly, we must notice various deposits of phosphate of lime. This substance is found among the crystalline schists of various regions, as Canada, where it is doubtless of inorganic origin. It also occurs, however, associated with various sediments, its existence in these being due to the agency of organisms. It is usually found in the form of irregular rounded nodules or grains of concretionary origin. These vary in colour, being usually different shades of brown, often approaching black. In Britain the chief deposits of commercial value occur in the Ordovician, Cretaceous, and Pliocene strata.

Phosphatic nodules of Ordovician age are found in the highest strata belonging to that system, on the north side of the Berwyn Hills, in North Wales. They form black nodules with a superficial graphitic glaze, in a matrix of calcareous mudstone belonging to the Bala series. As no vertebrates occur in these rocks, the presence of the phosphate has been ascribed to the agency of trilobites and brachiopods.

In the Cretaceous rocks phosphatic nodules are, or have been found in some quantity in the Lower Greensand, Gault, and Chalk.

The Lower Greensand nodules have been chiefly worked in a strip of country extending from Bletchley to the north of Cambridge, the chief pits having been excavated at Brickhill, Potton, and Wicken near Cambridge. They are usually of a yellow-brown colour, and frequently exhibit casts of fossils.

The Gault phosphatic nodules have been worked in Buckinghamshire. They occur especially in the Upper Gault, and are of a black colour.

The chalk phosphates occur at different horizons. At the base of the Cambridge chalk a thin, pebbly deposit known as the Cambridge Greensand contained abundant phosphatic nodules of a brown or blackish colour. Many of these were derived from the Upper Gault, which is here denuded, its phosphatic nodules remaining as pebbles in the beach deposit forming the base of the chalk.

In the Upper Chalk, near Taplow, a deposit rich in phosphate of lime has been discovered, the phosphate being disseminated in certain beds in the form of small brown grains.

Phosphatic nodules are found at the base of several of the Pliocene deposits, as the Coralline Crag, the Red Crag, and the Norwich Crag. Those at the base of the Red Crag have been extensively worked. They occur as brownish nodules in shell-bearing sands.

In addition to these ancient phosphatic deposits, which were doubtless formed owing to the abundance of reptiles and fishes in the sea when the deposits were being laid down, we may notice certain terrestrial accumulations of phosphate of lime of recent origin, due directly or indirectly to the droppings of sea-birds. The Peruvian guano is the best-known of these, though they are also found in several other tracts where the rainfall is slight. In addition to the actual accumulations of droppings, phosphates may be developed in the underlying rocks by addition from above; thus we find that in some regions coral limestone has been phosphatised in this way, and in one case a trachytic lava has been converted into a rock rich in phosphates by a similar process.

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